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GEORGE REID
Editor

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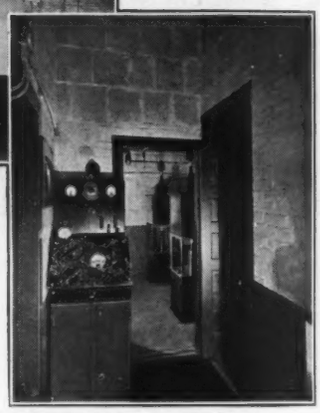
X-RAYED

Exposure room, showing X-ray tube stand — indicating flexibility of apparatus.

Exterior view — AMSCO X-ray Laboratory.



Control stand, looking toward machine room.

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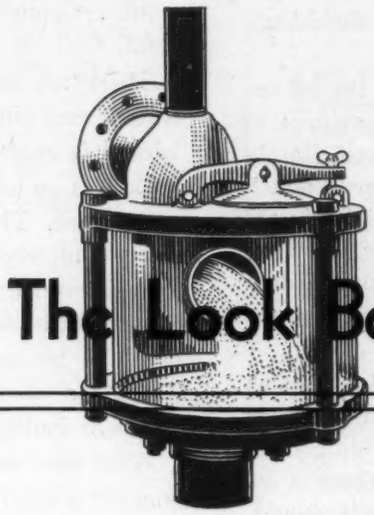

The Look Box

AS HAS BEEN customary for the past few years at the time of the annual meeting of the American Petroleum Institute, THE REFINER again devotes an entire issue to the presentation of the technical and engineering papers presented at this important convention. At each meeting the Refining Division of the Institute devotes three full sessions to technical and engineering progress reports and each year these technical programs grow more interesting, more valuable and hence more important to all those within the industry who are concerned with its progress and with the rapidity of its technical development. It is for this reason that the editors of THE REFINER feel it incumbent upon them to give its readers as much as possible of the engineering and technical information coming out of these important conferences, in the issue of current date with the meeting. This policy, upon which THE REFINER has many times been complimented, assures the readers that they will receive all of the important technical information presented at the American Petroleum Institute Division of Refining sessions under one cover and at an early date following the meeting.

A. P. I. Papers

The well rounded and important program at the Los Angeles meeting this month brings before the industry two discussions of polymerization processes. These are presented under the titles "The Thermal Process for Polymerizing Olefin-Bearing Gases" and "Thermal Conversion of Hydrocarbon Gases to Gasoline." Also, there are two excellent papers on lubrication and lubricating oils presented under the titles "Fundamental Chemical and Physical Forces in Lubrication" and "Practical Selection of Improved Lubricants." Another interesting subject is that of Diesel fuels which is discussed under the title "Fuels for High Speed Diesel Engines From the Refiner's Viewpoint." Still another subject which has proven of real interest to the industry is that of utilization of butane as an internal combustion engine fuel, and this is discussed under the title "Characteristics of Internal-Combustion Engines Operating With Butane."

INDUSTRY should cease its trembling before government and its cringing before public opinion. Its record is such that it need not be ashamed. Its duty is to set the record out for reading and claim credit for what it has done and proposes to do.

No Cause For Shame

Oil is guilty of this trembling, yet its record will stand beside that of government and not suffer by comparison. Today it delivers a gallon of gasoline, superior in quality to that of a decade back, at a lower cost. Meanwhile government delivers a supervision no

better than the brand of a decade ago and the cost is higher.

For a thousand dollars a citizen can buy an automobile better than one of three times that cost ten years back. But the vehicle of government has mechanism inferior to the brand of a decade back and the cost is in excess of ten years ago.

Gasoline and the automobile have freed men from their balliwicks, given them opportunity to enjoy life and made them masters over distance. The record is one for which these industries should not be ashamed.

Yet, how often is the advertising of the oil industry pitched in such a tempo. It is common to read the claims of superiority of products. Rarely does the writer of copy enlarge his vision to match that of the product of which he sings. The industry needs either executives with the courage to set its record in words that match its deeds or copy writers who comprehend the accomplishments of the industry.

For instance, the people of the United States should be told that this industry expects a profit on its capital and expects only by providing merchandise and service that deserve it. If there is inherent evil in profit, industry will die as it should. If there is no inherent evil in profit, then it is the duty of industry to state its claims in logic and words so convincing that the industry will gain prestige as it seeks profit. By withholding these claims the silence feeds the fires of those who spread the propaganda of the inherent evil in profit.

Some of the advertising space of this industry should be devoted to the cause of safety. High speed driving takes a teriffic toll of human lives. It eats gasoline and destroys machinery faster than sensible driving. Here is a field in which the industry can serve itself and its public to advantage.

Here is an industry from which a few million human beings draw their livelihood. The record is one of which the industry should not be ashamed. Why is the story so seldom told? Either fear or warped vision. Of these the industry should be ashamed and it stands convicted by its failure to speak its claims.

At best the statements of superior merchandise made dull reading. Some substantial oil company could contribute to progress by throwing half its advertising appropriation into messages which make no mention of merchandise. Let this part be a sincere statement of what the company contributes to the enjoyment and welfare of those it serves.

There is no occasion for boasting, still there is no call for meekness. An honest record justifies an honest statement and an honest reward.

Dollars' Wages

SOMEHOW the attitude of a few million human beings has been twisted into a complex to the effect that business is an evil. These men hold that there is something inherently wicked in the relationship whereby a man or a corporation with capital hires men to work.

The plea is that all men should be employed, at shorter hours and higher wages, that money owes more to men and men less to money. Capitalism is branded as a wicked instrument.

There are wicked men in business as well as wicked men outside of it. But to brand business as wicked is as cowardly as it is unreasonable.

Dollars go to work for the same reason that men go to work. They are sent forth to maintain themselves and return a profit. A man takes a job to gain necessaries for living and a surplus for saving. As soon as he saves a dollar and puts it in a savings bank, he become by that measure a capitalist and his dollar becomes as wicked as the dollars by which he had his living and made his saving.

What men should realize is that paying wages is no more wicked than receiving wages, that in a free country dollars must go to work if men go to work.

"Inspection" Reprinted

THE important series of articles recently completed in THE REFINER dealing with "Inspection of Oil Refinery Equipment" has been reprinted in book form and is offered, in limited numbers, to those desiring this valuable work at $1.00 per copy. This highly instructive work was prepared for publication exclusively in THE REFINER by Franklin L. Newcomb, supervising engineer, safety inspection division, general engineering department, Standard Oil Development Company. For many years Mr. Newcomb has been in active charge of all inspection work done for Standard Oil Company of New Jersey and its subsidiaries throughout the world, and his close contact with inspection work and developments in the various phases of such work, makes him especially fitted to treat this subject in both a comprehensive and understandable manner. The series of five full length articles met with excellent response, which, in turn, prompted their reprinting in book form. A few copies remain in stock at THE REFINER's home office in Houston, and this is the last "ad" that will be written about them.

(*Please see page 45a*)

Thermal Process for Polymerizing Olefin-Bearing Gases

M. B. COOKE, H. R. SWANSON,
Alco Products, Inc., New York
and
C. R. WAGNER,
The Pure Oil Company, Chicago

POLYMERIZATION of normally gaseous hydrocarbons has been studied in the laboratory for a quarter of a century, and is now being employed commercially to produce gasoline and aromatics. Motor fuel of a higher octane rating can be produced by polymerization than by any other accepted method of refining petroleum. The two commercial methods consist of the "thermal" process, wherein heat and pressure are employed to effect the reaction, and the "catalytic" process in which some heat is used but in which the reaction of polymerizing is accelerated by catalysts. At the present time several thermal plants are in successful operation, whereas only one commercial unit of the catalytic type has been operated. Both types of plants effect a union of unsaturated hydrocarbons, normally gaseous, to form a liquid boiling within the motor-fuel range. The octane value of the polymer product ranges from 78 to 110 when tested by the A.S.T.M. method. The blending value of the polymer is very high. The thermal process converts ethylene as well as propylene and butylene into polymer, whereas the catalytic methods so far made available do not polymerize ethylene to any great extent. Several different systems of the thermal process are described and data given.

This paper was presented at Sixteenth Annual Meeting, American Petroleum Institute, at Los Angeles, November 14, 1935.

THE demand for anti-knock fuel has been so great during the past few years that oil technologists have been searching intensively all possible methods and sources of supply. This study has been accelerated more recently by the demand for fuel for high-compression super-charged aviation motors with octane ratings far above anything which has been considered heretofore. Various schemes for cracking heavy oils have been proposed, and thousands of chemicals have been tried with the idea of their use as "dopes" to increase the anti-detonating characteristics of gasoline. Little attention has been directed toward the gases produced as a by-product from cracking operations, a prolific source of valuable anti-knock fuel.

Polymerization, and its application to hydrocarbon chemistry known for many years, may be defined as the union of two or more molecules of a substance to form a larger molecule, the latter being called a "polymer." Polymerization is sometimes incorrectly referred to as condensation. The olefins of low-molecular weight, viz., ethylene, propylene, butylene, etc., form polymerization products when subjected to heat and pressure without catalysts.

The significance of the polymerization of gaseous olefins is the production of gasoline-like hydrocarbons which, due to modern internal-combustion-engine designs and demands for fuel, serve as desirable fuels, or blending fuels, due to their inherent anti-detonating characteristics when used in such engines.

A search of the literature on polymerization reveals that there have been two plausible theories or explanations of the mechanism of polymerization of unsaturated hydrocarbons. The first theory was proposed when technologists were studying the mechanism of sulfuric-acid refining of hydrocarbon oils containing unsaturates, viz., that sulfuric acid forms first an acid ester or alkyl sulfuric acid by addition; this addition product subsequently reacts with another molecule of the olefin to form the polymer. The sulfuric acid is liberated, and theoretically may go through many cycles. If *iso*-butylene is polymerized as the olefin, di*iso*butylene (*iso*-octylene) would be obtained, which has twice the molecular weight of the raw material, butylene. The second theory is called the partial-valence theory. According to this theory the doubly-linked carbon atoms have partial valences or "residues of free affinity." The further assumption is made that the molecules contain a mobile or labile hydrogen atom (the assumption of a labile hydrogen atom has been made to explain many reactions) which shifts from one molecule to the other, thus permitting polymerization. This explanation may account for polymerization in the presence or absence of catalysts where no addition compounds are formed.

According to either of the above theories, two unlike molecules may also react—thus explaining the formation of all the higher polymers.

The above characterizes in general, from a broad chemical viewpoint, the process of polymerizing light hydrocarbons. The opinions with respect to the reaction mechanism of the conversion of specific constituents are divergent, and it is not considered within the scope of this article to discuss this in detail.

From an equipment-design standpoint, theoretical consideration of the kinetics of the reaction are of importance. Polymerization is generally assumed to be a

bi-molecular or second-order reaction. The reaction-velocity constant, k, is expressed by the equation:

$$k = \frac{x}{at(a-x)}$$

Where:

t = the reaction time
a = the reactant at the beginning of the reaction (t = 0), and
x = the part of the original reactant which is converted in the time *t*.

A consistent correlation of data will establish the values of the reaction-velocity constant as a function of the reaction temperature for any constituent. Correct and consistent reaction-velocity data are the prime requisite for the design of equipment of this type.

In the earlier literature on pyrolysis of hydrocarbons, the opinion is expressed that aromatics are only formed at extremely high temperatures—temperatures considerably above those to be disclosed as proper and sufficient in this article. Free-energy relationships, however, indicate that aromatics are formed from certain olefins of low molecular weight at as low a temperature as 800°F. The older literature referred to above mentions temperatures in the order of 1500-2000°F. When polymerizing at comparatively low temperatures and high pressure, the simple junction of molecules with the least disturbance of the existing carbon-to-carbon and carbon-to-hydrogen linkages seems to prevail, while at higher temperatures a complete re-arrangement seems to take place leading to the formation of cyclic compounds. The high temperature polymerization condensate is almost completely aromatic.

Heretofore attempts to form aromatics from low-molecular-weight hydrocarbons have been largely confined to pyrolysis of paraffin gases, an endothermic process. We are discussing here a process for polymerizing olefins, an exothermic reaction. It is, therefore, possible that local points of very high temperature exist at the time of formation of aromatic molecules, but the surrounding gases conduct the heat away rapidly enough to maintain a lower average temperature.

REFINERY OPERATING ECONOMY

The polymerization of olefinic gases for the production of low-sulfur aromatic compounds is destined to increase in importance. High anti-knock-value gasoline, or gasoline-blending material—as well as benzol, toluol, and xylol—can be made with good yields, and at a profit, at the present time. The trend of refinery cracking has been, and still is, from low temperatures (liquid phase cracking) to higher temperatures with a corresponding decrease in pressures. This tendency has resulted in an ever-increasing gas yield of higher unsaturation. This is ideal for polymerization, as an otherwise wasted (or nearly so) by-product—gas—becomes a valuable charging stock. The refiner can now install a polymerization plant, and the cost of it can be paid for, in one year or less, out of its earnings. The average refiner can increase his cracked gasoline output by polymerization by 15-20 percent if he polymerizes all his cracking still gases. This material has a very high blending value, and can be made either high in volatility or low in volatility. This flexibility gives the choice of employing high percentages of butane in the blended gasoline; or, if the material available for blending has low volatility, the necessary volatility may be obtained to a large degree from high volatility polymer gasoline.

The equipment for carrying out the process is similar in appearance, operation, and instrumentation to cracking still equipment—and for this reason few additional men are needed if the polymerization plant is installed close by, or in conjunction with, the cracking stills. Treating of the distillate is no different from treating other gasoline distillates, and no special processes are necessary.

On the contrary, most polymer distillate is lower in sulfur content than cracked or straight-run gasoline.

The most logical program to follow in this country in adopting polymerization consists of installing plants first to polymerize vapor phase cracking still gases. These are rich in unsaturates, and are amenable to polymerization at a very reasonable cost. By including a pyrolysis step, a very high ultimate yield of polymer gasoline is obtainable from this source of raw material. The liquid phase cracking still gases are, in general, rich enough in unsaturates to merit one step of polymerization before a pyrolysis step.

A second source of polymerization raw material is the huge quantity of natural gasoline tops and natural gas which is available. Natural gasoline tops will yield high percentages of polymer gasoline when dehydrogenated and polymerized. Natural gas can be used as a raw charge material for polymerization, but the yield of gasoline is less.

When it is considered that our gasoline production can be increased from 10-25 percent (of our total consumption) from the same amount of crude oil per day, it is highly important that this conservation step be pushed and encouraged most vigorously.

CHARGING STOCKS AVAILABLE

Commercially feasible charging stocks for gas polymerization for the production of motor fuel contain hydrocarbons varying from the lowest member of the paraffin series, methane (CH_4), to the normally gaseous butylenes of four carbon atoms. The methane group is found in refinery gases, and constitutes the major portion of natural gas. The modern polymerization plant can utilize any of this raw material in such a way that the gasoline produced will be a very substantial part of the total gasoline production.

The gases available as charging stock may be divided into three main classes, for convenience in arriving at yield figures. The most easily polymerizable gases are formed in the vapor phase cracking of hydrocarbon oils. In this country there are approximately 90 plants, each of which yields an average of 1.2 million cubic feet of highly unsaturated gases per day. Since the unsaturated content is high, no pyrolysis of the gases before the polymerization operation is necessary. Table 1 shows analysis of typical residue gases from a vapor phase cracking system.

TABLE 1

Analysis of Gyro Vapor-Phase Gas

Constituent	Sample No. 1 (Mol Percent)	Sample No. 2 (Mol Percent)
$CH_4(+H_2)$	32.5	37.9
C_2H_4	23.9	25.6
C_2H_6	13.4	13.8
C_3H_6	16.8	16.8
C_3H_8	4.9	3.1
C_4H_8	6.1)	
C_4H_{10} and heavier	2.4)	2.8
Specific gravity (air = 1)	1.035	0.95

Typical comparisons of the overhead from a stabilizer, working in conjunction with a Gyro vapor phase cracking and compression gasoline recovery system, are given in Table 2.

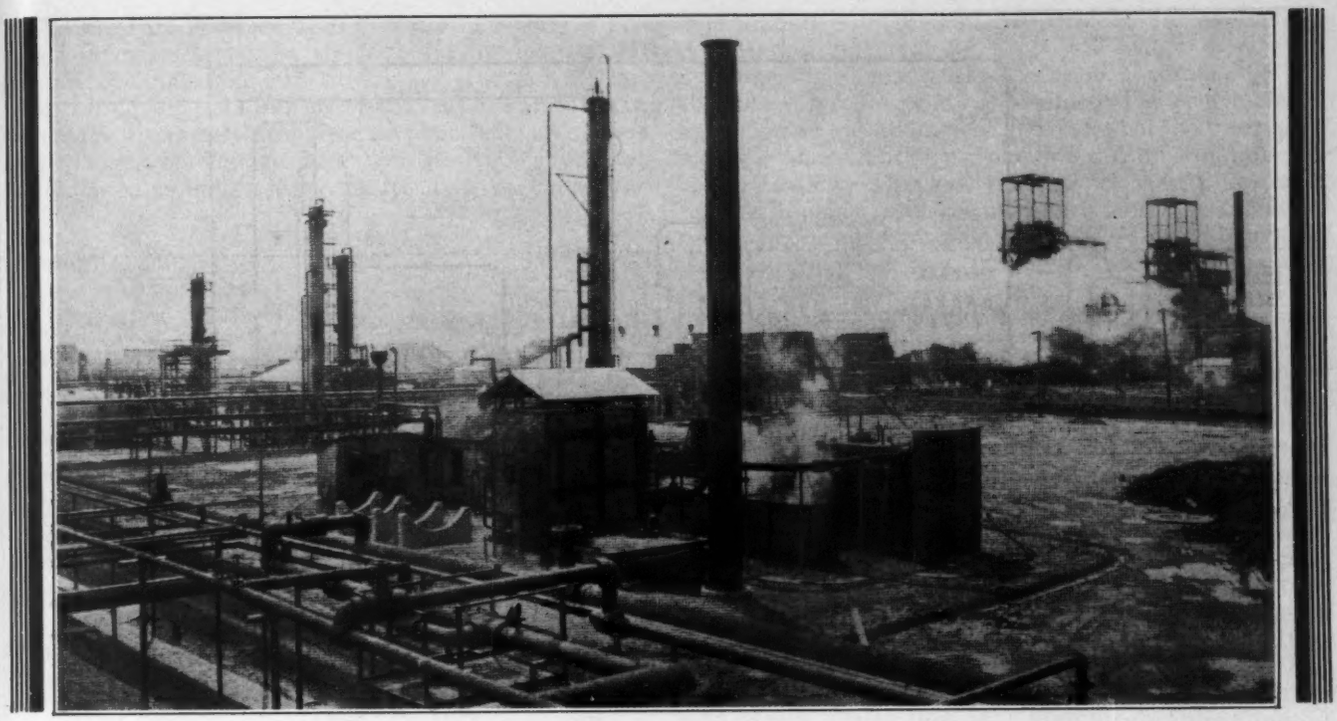

FIGURE 1
Polymerization Plant—The Pure Oil Company, Toledo, Ohio

TABLE 2
Analysis of Stabilizer Overhead

Constituent	Sample No. 1 (Mol Percent)	Sample No. 2 (Mol Percent)
CH_4+H_2	0.5	1.2
C_2H_4	9.2	7.1
C_2H_6	8.3	7.8
C_3H_6	40.3	37.6
C_3H_8	10.4	11.6
C_4H_8	28.4	30.5
C_4H_{10}	2.6	3.4
C_5 and heavier	0.3	0.8
Unsaturates	77.9	75.2

The amount of stabilizer gas in percent of the total residue gas will vary considerably, depending upon the method of gasoline recovery employed in connection with the vapor phase cracking system.

The above gases may be handled in two ways:

a. Compressed and charged as compressed gases to the polymerization coil (see Figure 2);

or

b. A major portion of the residue gas may be recovered as stabilizer overhead in liquid state and pumped to the polymerization unit (see Figure 3).

When charging a gas of the composition shown in Table 1 (vapor phase cracking gas) the entire gas is compressed to 600-800 pounds pressure and heated to 900-1000°F. in a pipe coil heater.

The gas is soaked in a reaction chamber which may take the form of a coil, which is cooled in order to absorb the exothermic heat of reaction, and then chilled by injection of either cold gas or oil. The reaction is checked at about 60-70 percent conversion, necessitating a recirculation ratio of about 1.5.

The mixture is fractionated, and the liquid product stabilized—giving a yield of gasoline of about 3.25 to 4.5 gallons per 1000 cubic feet when operating under these conditions. The data obtained from a typical run are given in Table 3.

TABLE 3

Charging Stock:	
Residue gas from Gyro vapor phase cracking system:	
Specific gravity (air = 1)	1.06
Unsaturates, percent	47.2
Yields of Products:	
Treated gas:	
Cubic feet per cubic foot of charge	0.80
Specific gravity (air = 1)	0.87
Unsaturates, percent	18.4
Liquid:	
Gallons per 1000 cubic feet of charge	4.4
E. P. Gasoline:	
Gallons per 1000 cubic feet of charge	3.7
Gravity, °A.P.I.	52.4
Percent of total liquid	84
ASTM Distillation of E.P. Polymer Gasoline in °F.	
Initial boiling point	96
10-percent point	134
50-percent point	220
80-percent point	302
End point	420

These data reveal that about 28 percent of the residue gas from the vapor phase cracking unit is converted to polymer gasoline when operating under the conditions outlined.

We estimate that there are 90 vapor-phase cracking units in the United States with an average capacity of 1000 barrels per day of reduced crude. The gas produced from these units amounts to approximately 100,000,000 cubic feet per day. If this quantity of gas were polymerized, with yields of E.P. gasoline conservatively estimated at 3.25 gallons per 1000 cubic feet of gas charged, there would be produced 325,000 gallons or 7800 barrels per day. This polymer gasoline contains about 25 percent of aromatics, is highly volatile, and has an octane value, by the ASTM method, of 78-80, and a blending value of 96.

This process does not produce the maximum of aromatics. In order to produce the maximum aromatic content, it is necessary to operate under other temperature-pressure conditions as described later.

The alternative operation mentioned above consists

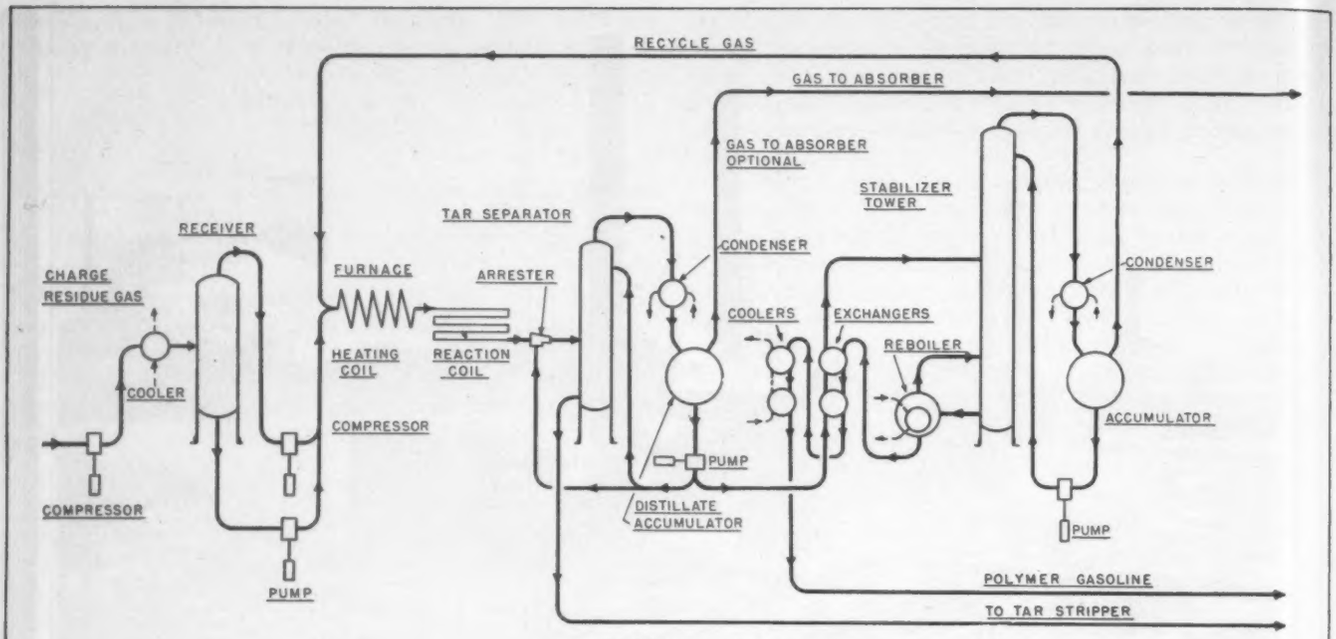

FIGURE 2
Gas-Charge, High-Pressure—Low-Temperature

of utilizing to the utmost the advantages of liquid charging stock for the polymerization operation. In this operation the gases from the vapor phase cracking operation are processed to eliminate the lower-molecular-weight saturates (C_1 and C_2) so far as is practical, and to concentrate the active olefins. Many advantages result from this procedure: 1, lower power costs due to the great reduction in horsepower for compression of gases in charging the polymerization unit; and, 2, the reduction in the plant investment due to reduction in size of the several pieces of equipment as a result of eliminating the inactive gas from the cycle. A third, and very worthwhile, advantage is realized at the same time in that the uniform control of the polymerization reactions becomes very simple.

The process of preparing the charging stock consists either in absorbing the higher-molecular-weight constituents of the cracked gas and recovering them from the absorbing medium under high pressure as a liquid, or in separating and fractionating directly under pressure—requiring compression of the cracked gas and fractionation of the condensed portion. When using these methods, the amount of ethylene in the charging stock is relatively small, since it would require very high pressures or low temperatures to get it in the liquid phase. However, the gasoline yield is only slightly reduced, since ethylene polymerizes too far—forming tar if the reaction is carried out at the proper temperature for the propylene-butylene reaction. The temperatures and pressures employed are within the same ranges as given in the case of the gas-charging operation. Typical data of the liquid-feed operation are found in Table 4.

TABLE 4
Liquid-Feed Polymerization Operation

Commercial plant handling 4,050,000 cubic feet (standard) per day. Average operation, September 1 to September 20, 1934.

Charging Stock (Including Recycle):	
Specific gravity (air = 1)	1.51
Unsaturates, mol percent	49.4
Conversion of unsaturates, percent	86.7
Recycle ratio	1.75
Yield and Properties of Products:	
E.P. gasoline:	
Gallons per 1000 cubic feet of fresh charge	8.8
Gravity, °A.P.I.	55.0
Octane No., ASTM	76.0
ASTM Distillation in °F.	
Initial boiling point	90
10-percent point	105
30-percent point	145
50-percent point	182
90-percent point	323
End point	398
Fuel oil:	
Gallons per 1000 cubic feet of fresh charge	3.0
Gravity, °A.P.I.	8.0
Treated gas:	
Specific gravity (air = 1)	1.01
Unsaturates, mol percent	22.0

HIGH-TEMPERATURE—LOW-PRESSURE POLYMERIZATION

By the high-temperature—low-pressure method of operation, good yields of gasoline can be obtained. The gas is compressed to feed pressure and heated. Temperatures existing in the reaction coil range from 1150° to 1300°F., and pressures are in the order of 50 to 75 pounds per square inch, gauge.

Operating on absorber gas, the unsaturates in the gas are predominantly ethylene, and give yields of distillate from three to 4.5 gallons per 1000 cubic feet employing recirculation as indicated by the test data in Table 5.

TABLE 5

Operating Conditions:	
Once-through operation:	
Temperature of coil outlet, °F.	1275
Pressure of coil outlet, lb. per square inch, gage	60
Conversion, percent	37.4
Charging Stock:	
Specific gravity (air = 1)	0.79
Unsaturates, percent	39.4
Distillate Made:	
Gallons per 1000 cubic feet	1.75
Gravity, °A.P.I.	21.6
Percentage boiling up to 350°F.	76
Octane No., ASTM	102
Treated Gas:	
Cubic feet per cubic foot of gas charged	0.85
Specific gravity (air = 1)	0.72
Unsaturates, percent	29

The yield of distillate at the rate of conversion obtained in cyclic operation would be approximately 4.0 gallons per 1000 cubic feet.

Operating on stabilizer overhead, the unsaturates in the charge are mostly propylene and butylene, and yields of distillate from eight to 12 gallons per 1000 cubic feet are obtained as indicated by the test data in Table 6.

TABLE 6

Operating Conditions:		
Once-through operation:		
Temperature of coil outlet °F.		1175
Pressure of coil outlet, lb. per square inch, gage		55
Conversion, percent		80
Charging Stock:		
Specific gravity (air = 1)		1.352
Unsaturates, percent		79.6
Distillate Made:		
Gallons per 1000 cu. ft.		98
Gravity, °A.P.I.		26.4
Percentage boiling up to 350°F.		68
Octane No., ASTM		86
ASTM Distillation in °F.:	Distillate	350 E.P. Gasoline
Initial boiling point	118	120
10-percent point	184	172
30-percent point	218	190
50-percent point	256	204
70-percent point	368	224
90-percent point	...	267
End point	...	352
Treated Gas:		
Cubic feet per cubic foot of gas charged		0.46
Specific gravity (air = 1)		0.86
Unsaturates, percent		34.5

The yield of distillate for cyclic operation would be approximately 11.0 gallons per 1000 cubic feet. The percentage boiling up to 350°F. can be increased by operating at a lower rate of conversion per pass.

The yield of distillate seems to be somewhat higher for the low-temperature—high-pressure operation than for the high-temperature—low-pressure operation when operating on the same charging stock, but the yield depreciation is more than compensated for by the appreciation in quality.

In the high-temperature operation a gasoline of 85-105 octane No. (ASTM) is obtained. The octane-blending value is approximately 105-125. The polymer produced is almost entirely aromatic; and the volatility, of course, is low. The low volatility is a very desirable feature in many instances, inasmuch as the octane number of the blended gasoline may be very much increased without removing any butane before blending with polymer gasoline.

To obtain the maximum polymer gasoline possible from a given quantity of by-product gases, a combination of pyrolysis and polymerization steps seems to be ideal. This system gives the maximum yield of high-quality polymer gasoline from charging stocks which originate from gasoline-cracking stills of the liquid-vapor-phase types. In the case of liquid-vapor-phase gas, it is estimated that there are produced 1,000,000,000 cubic feet per day. If this high-temperature—low-pressure combination system were used, there could be produced over 1,200,000,000 gallons per year of 100-octane gasoline. This distillate is 80 to 85 percent aromatic. Therefore, there could be produced over 1,000,000,000 gallons of relatively pure aromatics per year, or 24,000,000 barrels per year.

A simple illustration of a high-temperature process, comprising a pyrolysis and a polymerization step, is given in Table 7 (natural gas as the original charging stock is used).

The treated gas is lower in gravity and has a lower heating value, which makes it more desirable for use as a domestic or other heating gas.

Natural gas produced in this country in 1933 amounted to 1,555,474,000,000 cubic feet. The figures for 1934 are not yet available, but are probably higher. In 1932 there were produced 2,555,000,000,000 cubic feet. Taking the 1933—and more conservative—figures as a basis for figuring the potential polymer gasoline, and assuming the average composition to be the same as given in Table 8, we could obtain 2.1 gallons of 350-E.P. distillate per 1000 cubic feet, or 2.1×1,555,474,000=3,270,-

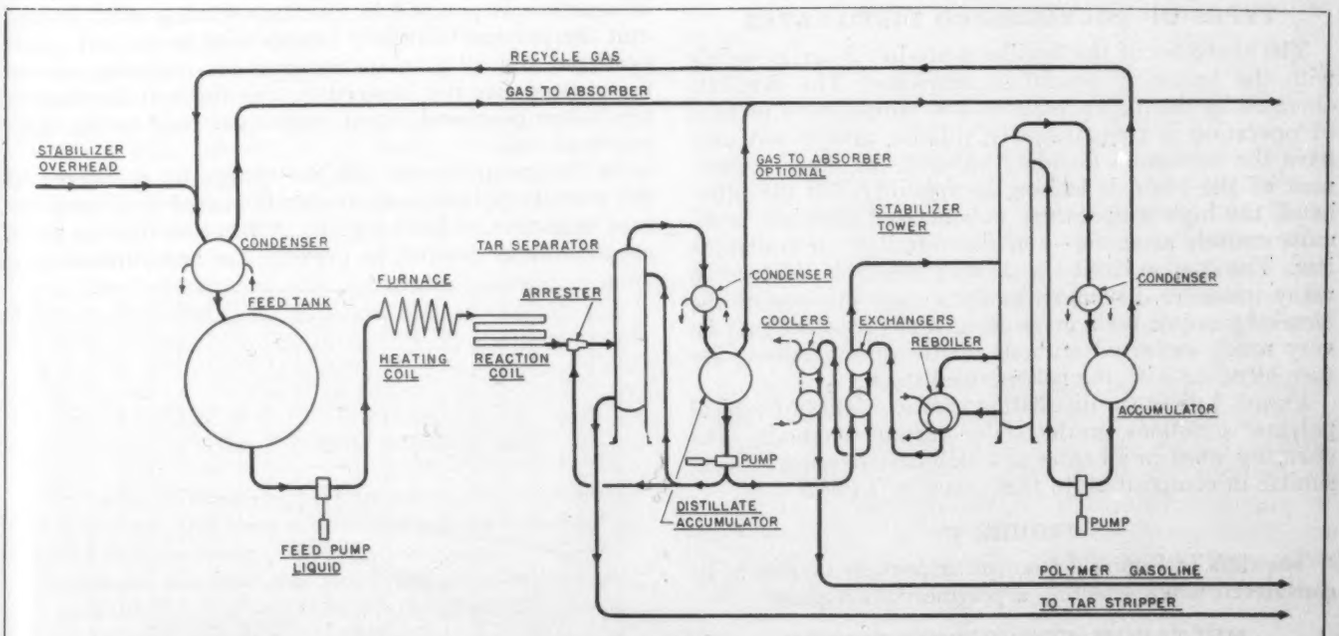

FIGURE 3

Liquid-Charge, High-Pressure—Low-Temperature

000,000 gallons per year (77,800,000 barrels per year). There would still remain 1,414,000,000,000 cubic feet for domestic or industrial use as a heating medium.

The potential yield of polymer gasoline from refinery and natural gas in this country, utilizing the thermal process with efficiencies obtainable at this time, amounts to approximately 110,000,000 barrels per year, or roughly 25 percent of the total gasoline consumed in the United States during the year 1934. The octane value is higher than that obtained by any other known thermal or catalytic process for producing gasoline. Only tetraethyl lead may be considered a competitor for enhancing the anti-knock value of gasoline—and this material does not increase the amount of gasoline to be used as fuel, but only alters and improves the anti-knock quality.

TABLE 7

Charge:	
Specific gravity (air = 1)	0.815
Composition:	(Mol Percent)
CH_4	70.5
C_2H_6	12.7
C_3H_8	10.3
C_4H_{10} and heavier	6.5
Pyrolysis Gas:	
Specific gravity (air = 1)	0.645
Composition:	(Mol Percent)
H_2	11.5
CH_4	62.5
C_2H_4	15.7
C_2H_6	5.1
C_3H_6	2.5
C_3H_8	1.2
C_4 and heavier	1.5
Liquid Made:	Gallons Per 1000 Cubic Feet of Charge
Pyrolysis step	0.42
Polymerization	2.38
Total	2.80
Percentage boiling up to 350°F.	75
Octane No., ASTM	104
Treated Gas:	
Cubic feet per cubic foot of gas charged	0.91
Specific gravity (air = 1)	0.59

TYPES OF POLYMERIZED DISTILLATES

The character of the distillates produced varies widely with the operating conditions employed. The distillate obtained by the high-pressure—low-temperature method of operation is comparatively volatile, and would only have the maximum blending value if the other component of the blend is lacking in volatility. On the other hand, the high-temperature polymerized distillate is almost entirely aromatic—and the volatility, of course, is low. The low volatility is a very desirable feature in many instances, inasmuch as the octane number of the blended gasoline for a given Reid vapor pressure may be very much increased without removing any butane before blending with the polymerized stock.

Figure 4 gives the distillation characteristics of typical polymer gasolines produced by various methods. The charging stock in all cases is a stabilizer overhead stock, similar in composition to that given in Table 2.

FIGURE 4

The data in Figure 4 bear out important factors to be considered when selecting a polymerization plant.

MULTI-COIL CONVERSION SYSTEM

A residue gas from a pressure liquid-vapor-phase cracking system, which is comparatively low in unsaturates, should be processed in a system involving three unit operations if the maximum yield of high octane distillate is desired:

1. High-temperature—low-pressure polymerization of propylene and butylene.
2. Pyroylsis of gas remaining after the polymerization step.
3. High-temperature—low-pressure polymerization of the cracked gases.

Let us select a typical charging stock of this type as found in most refineries in the form of stabilizer overhead gases, which contain—we shall assume—only about 30 percent of unsaturates. By polymerizing as a first step, we have the advantage that we can operate under the most favorable temperature and pressure conditions for the conversion of the propylene and butylene to polymer gasoline. The stabilizer overhead gases are already under pressure and, by proper cooling, are liquefied as a by-product of the stabilizing operation—thus eliminating the installation of large compressors to feed the polymerization unit. Fig. 5 shows the various phases of operation, and indicates the essential equipment.

In the primary polymerization step the charge is heated to the proper temperature, and enters the reaction coil which is designed to give the desired time-temperature effect. Cooling means is provided to keep the temperature within the proper limits. The reaction products, immediately upon leaving the coil, are chilled to stop any further reaction, and simultaneously are cooled to a temperature low enough so that heavier products will be dropped out in the tar separator. Gases, distillate vapors, and chilling medium forming the overhead from this separator are refluxed for end-point control. The total overhead passes to a cooler and accumulator where the chilling medium, polymerized distillate, and a portion of the gaseous constituents are condensed. The uncondensed gases and vapors from the accumulator are passed directly to the gas-pyrolysis unit.

A portion of the condensate from the accumulator is used as the chilling medium previously referred to; and the remainder, equivalent to the condensed products of reaction, is pumped to the fractionating unit. In this unit the polymer distillate is stabilized to desired specifications, and all gaseous compounds—including excess C_4 constituents not desired in the finished distillate—are taken overhead form additional feed to the gas-pyrolysis coil.

In the gas-pyrolysis coil the charge as recovered in the primary polymerization step is heated to a temperature in excess of 1300 deg. F. A reaction time as short as possible is desired to prevent the unsaturates once

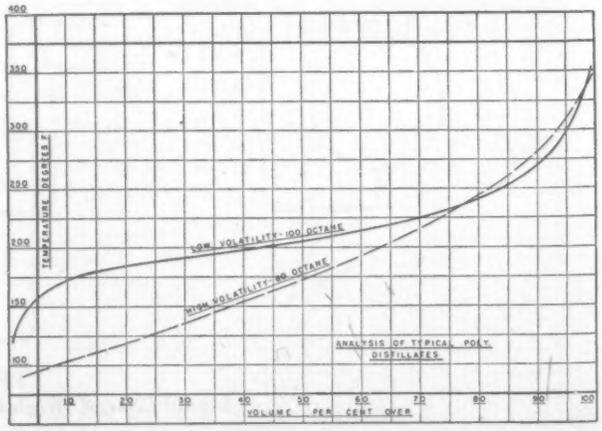

FIGURE 4

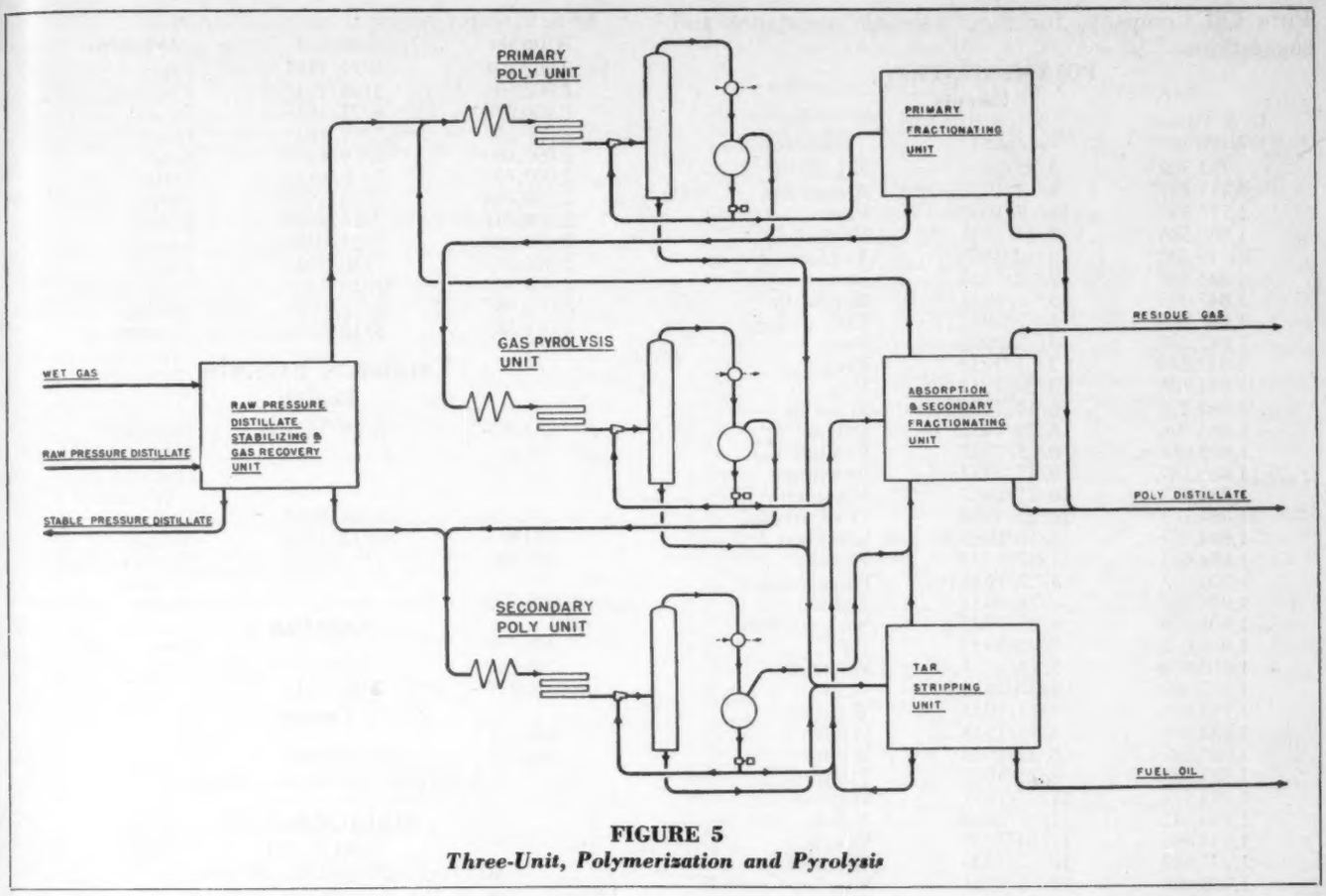

FIGURE 5
Three-Unit, Polymerization and Pyrolysis

formed from entering secondary reactions leading to the formation of tar. The products of reaction are chilled to a temperature low enough to liquefy compounds in the fuel-oil and tar range. Gases, distillate vapors, and vaporized chilling oil pass overhead from the tar separator to a condenser and accumulator, where the chilling material is condensed. The gas remaining after compression and cooling is charged to the secondary polymerization coil, and submitted to a high-temperature—low-pressure reaction. The chilling of the conversion product, tar separation, condensing of chilling medium, is analogous to the method used in the primary polymerization step. Since the reaction products contain a high percentage of hydrogen and methane, recovery of polymer distillate cannot be effected by condensation under the low operating pressure. Recovery may be accomplished by compression and subsequent condensation. However, in most cases it is believed that absorption will be more economical. All polymer distillate distilled from the absorption oil is accumulated and fed, together with the pyrolysis distillate, to the secondary fractionator. The bottom product from this unit is stabilized to desired specifications, and the light overhead material is passed directly under its own pressure to the primary polymerization unit as re-cycle.

The bottoms from the various tar separators are combined, heated, and then stripped of all fractions of gasoline of boiling range.

A unit of the type described above is very flexible, and insures the highest yield of distillate for charging stocks varying widely in composition.

COST OF PLANTS

It has already been mentioned that polymerization plants are similar in appearance and operation to cracking plants, especially so if the cracking plant is modern and is equipped with gasoline-recovery and stabilization units. The cost of construction and operation is likewise very nearly the same as it is for the modern cracking installation. The only other worthwhile item affecting the cost of producing polymer gasoline or aromatics is the value of the charging stock to the polymerization unit. In this case it is a residue gas and, in general, its cost is measured by its heating value, since it is used instead of other heat-producing products such as fuel oil. It is safe to assume, in the majority of cases, that the charge gas carries a value equal to fuel oil in a given locality. It should also be considered that gas from refinery operations cannot be shipped to market, in most cases, without purification—and then only if pipe lines are available. It appears entirely fair, therefore, to give the gas-charging stock a maximum value not exceeding heavy fuel oil. With this as a basis, it is found that polymer gasoline can be produced in this country at a cost not exceeding 5 cents per gallon at the present time.

If we consider the production of highly-aromatic polymer distillate, it is quite evident that we have the cheapest source of aromatics so far made available. The general conclusion to be drawn, as regards the economics involved, is that polymerization is a very attractive commercial process for refiners to install. As the demand for anti-knock fuel increases, the returns from polymerization likewise increase.

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Thermal Conversion of . . . Hydrocarbon Gases to Gasoline

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IN the United States there are in operation well over 25,000,000 automotive engines which consume approximately 1,260,000 barrels of gasoline per day. While there is an obvious connection between the properties of the gasoline, the design of the motor, and the cost of operation, the economics of the situation have not thus far given impetus to great changes in either gasoline characteristics or motor design—with certain few expections. Moreover, while cooperation exists between refiners and motor manufacturers to effect concordant improvements in motors and fuel, progress has not been rapid. The processes presently employed in the manufacture of gasoline, cracking, and distillation —while adequately meeting the present requirements— are for the most part carried out with little control over the type and content of the specific compounds constituting the final product.

However, impelled both by the desire to increase product sales and by scientific incentive, petroleum technologists have been actively developing new types of motor fuels possessing properties that are intriguing and attractive to the automotive designer, the motor-fuel manufacturer, and the motorist alike. These developments naturally incur the use of different processes and, in certain cases, new raw materials. Refiners have long desired to employ, in the manufacture of motor fuels, the normally-gaseous refinery residues as well as natural gas, which is available in such great quantities. It was obvious that the successful utilization of natural gas for this purpose would open up a vast field in which the raw stock was both abundant and cheap; the use of refinery gas was attractive because of the natural desire to enhance the value of this invariable and undesirable result of cracking.

RESEARCH ON HYDROCARBON TRANSFORMATIONS

Research on both these types of gases indicated, first, the possibility of producing from them—substantially by controlled chemical synthesis — motor fuels whose performance characteristics lay entirely outside of those which would normally result when manufacturing gasoline by conventional refinery processes. A second result of this work was the appreciation that these new fuels had potential possibilities in modifying, and probably accelerating, the evolution in automotive-engine design that gradually is taking place with resultant improvement in efficiency and performance.

For practically two decades the technical and patent literature on refining has been replete with references bearing on this general subject of converting hydrocarbon gases to liquids. The published data on the decomposition and polymerization of the olefinic hydrocarbons up to 1930 has been admirably summarized by Egloff, Schaad, and Lowry.[105] The more important data published on the pyrolysis and polymerization of low-molecular-weight hydrocarbons have been reviewed by the writers in the course of a general literature search on this subject, and a list of references is appended.

A mental picture of all these data inclines one to classify the principal processing methods reported into five general groups. These are:

1. *High-temperature, low-pressure gas cracking into unsaturates.* When such a process is carried out primarily for the manufacturer of motor fuel, the cracking obviously must be followed by polymerization.

Typical of this work has been that of Cambron and Bayley,[10, 11] Dunstan et al.,[13, 14, 15] Frey et al.,[21, 22, 23] Frolich et al.,[24, 25, 26] Hurd et al.,[32, 33, 34] Neuhaus et al.,[51, 52] Pease et al.,[58, 59, 60] Rice,[65] Sullivan.[73]

2. *High-temperature, low-pressure pyrolysis of saturates and unsaturates primarily to produce aromatics.* Typical of these methods is the work of Cambron and Bayley,[90, 91] Dunstan et al.,[97, 98, 99, 100, 101, 102] Frey et al.,[109, 110] Podbielniak,[143, 144] Zanetti,[167, 168 169]

3. *Non-catalytic polymerization of gaseous olefins,* as reported by Dunstan,[176, 177, 178, 179] Ipatieff,[180, 190] Sullivan,[207] Wagner.[210]

4. *Catalytic polymerization of gaseous olefins,* as investigated by Gayer,[214] Ipatieff et al., [217, 218, 219, 220, 221, 222, 223, 224, 225] Waterman.[244, 245, 246, 247]

5. *Methods such as alkylation for affecting the combination of saturates and unsaturates,* as shown by the work of Ipatieff et al.

It is apparent that research on the first four general groups has been characterized by: *a,* the assumption that the saturated compounds are so chemically inert that some degree of unsaturation must be effected before the components can be processed effectively; *b,* the placing of emphasis on the so-called once-through operations (work recently reported by Wagner is a distinct exception to this); and, *c,* the importance given to the production of aromatic compounds.

The reactions in the fifth group differ from those of the other classifications in that: 1, it is indicated that under certain conditions the supposed chemical inertness of saturated compounds may be overcome and they may be made to act directly; and, emphasis is shifted, to a considerable extent, from the production of aromatic compounds to that of aliphatics and relatively stable olefins—although such a process may be operated to produce aromatics at a sacrifice of other characteristics. However, most of the data reviewed refer to once-through operations — although Tropsch, Wagner, and others have pointed out that increased yields may be expected from a re-cycling operation.

DEVELOPMENT OF THE UNITARY PROCESS

This analysis of the data disclosed little published material descriptive of one very interesting field, viz., a unitary non-catalytic process for the production of motor fuels from either natural or refinery gases.

The present discussion deals with certain results of cooperative effort on hydrocarbon transformations from which such a distinctive process for the manufacture of motor fuels possessing valuable properties has been evolved. These data do not infer that, depending on the constitution of the feed stock, certain other combinations involving multi-coil operation may not be desirable. One such possibility could consist of a two-stage process in which the charge would be first subjected to polymerization conditions, followed by separation of liquids—and a second step, consisting of substantially a unitary process for converting the residue. Another alternative would be, of course, low-pressure, high-temperature cracking of the feed, followed by high-pressure polymerization, with separation of liquids, succeeded by a unitary process. Other combinations may be used as required, but it is believed that in a majority of cases the unitary operation will show a preferred economic advantage.

Several years ago experimental data, as yet unpublished, on the reaction rates of the pyrolysis of mixtures of hydrocarbins obtained in the laboratories of certain of the companies now in the Polymerization Process Company group, suggested a method of attack, generally different from those that had been proposed, in which the raw charging stock was to be treated as a liquid, rather than gas, and processed specifically in the highly-condensed phase.

The factual basis for this entire development rests, aside from authentic published data, on the following:

A. Single-pass runs at pressures varying from atmospheric to 4500 pounds per square inch.

B. Re-cycling pilot-plant operations over the complete pressure and temperature range permitted by available materials of construction.

C. Full-scale commercial operation at the Alamo refinery of the Phillips Petroleum Company at Borger, Texas.

D. The use of feed stocks in the above operations varying from pure ethane, propane, and butane (and mixtures thereof) to the complex mixtures found in stabilizer reflux and absorber-oil distillates.

Aside from leading to the inference that a unitary process possessing certain of the characteristics of a conventional gas-oil cracking operation would have important advantages in gas cracking and polymerization, these data indicated the following:

a. Gas cracking is essentially an apparent first-order reaction; polymerization is distinctly a second-order effect; and both obey the conventional physico-chemical laws governing such reactions.

b. Polymerization and cracking may be effected simultaneously by proper choice of conditions.

c. The relative rates of cracking and polymerization may be so controlled that the required olefin production for re-cycling may be obtained without substantial naphtha degradation.

d. Direct conjugation of saturates with unsaturates may be effected at reasonable rates.

e. Liquid yields of over 14 gallons (net) per 1000 cubic feet of gaseous feed (60°F. and 30 inch mercury) may be obtained with either high or low volatility and having octane-blending values varying from 80 to over 120 C.F.R. motor method.

RE-CYCLING PILOT-PLANT RESULTS

In that portion of the development of the unitary method of hydrocarbon conversion which was carried out on a pilot-plant re-cycling basis, the range of operating variables chosen was dependent on the limits imposed both by the reactions inherent in the process and by the physical limitations imposed by the materials of construction available or most economical. During most of these runs the fractionating system of the pilot plant operated to afford imperfect separation of C_2 and C_3 constituents—and, therefore, a true re-cycling operation did not obtain. However, the off-gas stream and the cycle stock were both subjected to low-temperature analysis, and the observed yields were calculated to a "net" basis to eliminate variations due to changes in the efficiency of the gas-recovery part of the pilot plant—a translation of the results that would obviously not be necessary in the case of a commercial unit designed for maximum operating efficiency.

Further—because in every case investigated there was a net production of hydrogen, methane, and ethylene—it has been assumed, when calculating the possible liquid production from propane and butane, that the former three compounds were not a source of gasoline. Therefore, net yield is defined as the yield realized based upon the C_3 and C_4 fractions disappearing. In another part of this paper there is presented evidence showing direct juncture of saturates with unsaturates, and the assumption is made that the C_2 compounds derived from cracking propane and butane do enter into the reactions which result in the production of liquids boiling in the gasoline range. Unquestionably this assumption is open to doubt, but the purpose of this procedure was to afford no advantage to the conclusion that saturate to unsaturate juncture had taken place.

A series of four pilot-plant re-cycling runs, on which the raw feed consisted of stabilizer reflux, are first presented as representative of typical operating results (see Table 1).

TABLE 1
Re-cycling Operation

Run No.	772	861	903	942
Pressure, lb. per sq. in.	800	1200	1200	1200
Temperature, deg. F.	1000	1000	1100	1030
"Net" yield, percent by weight	67.9	69.0	69.6	64.5
Weight, percent of saturates in feed (net)	57.0	54.0	60.7	59.9
Weight, percent of unsaturates in feed (net)	43.0	46.0	39.3	40.1
Net yield as percent of unsaturates in fresh feed	158	150	177	161
Gallons of liquid per 1000 cu. ft. net gaseous feed	12.78	13.10	14.40	13.5
Gross feed, percent by volume:				
C_2H_4	3.4	1.9	2.4	2.0
C_2H_6	12.2	6.8	9.6	6.5
C_3H_6	29.6	30.5	21.3	21.0
C_3H_8	46.3	49.8	38.8	39.6
C_4H_8	4.3	4.8	11.0	13.6
C_4H_{10}	4.2	6.2	16.9	17.3
Net feed, percent by weight:				
C_3H_6	43.0	41.1	23.1	20.3
C_3H_8	57.0	54.0	36.4	37.1
C_4H_8	...	4.9	16.1	19.8
C_4H_{10}	...	....	24.3	22.8
Blending value of 400-EP distillate, 50 percent in "A" reference fuel, octane number C. F. R. M.	92	90	83	88

From these data it will be observed that:

1. The potential yields, whether expressed as gallons of liquid per 1000 cu. ft, of feed measured as gas (12.8-14.4 gal.) or as weight percent on charge (64.5-69.6 percent) are very high.

2. These yields show a conversion of upwards of 150 percent of the unsaturates in the feed, thus indicating in the first instance concomitant polymerization of unsaturates and cracking of saturates; the later at rates which were not conventional for the temperatures employed. That some direct reaction of saturates with unsaturates undoubtedly takes place in such operations will be demonstrated hereinafter.

Moreover, these runs demonstrated the feasibility of a

process which in effect may be considered an economic compromise between cracking and polymerization.

DIRECT REACTION OF SATURATED AND UNSATURATED COMPOUNDS

In other runs evidence of direct reaction of saturates with unsaturates had been obtained, and to test this deduction a series of once-through runs was made in which the temperatures were kept well below those at which cracking of saturated hydrocarbons would be material, i.e., 800°F. and 850°F. The charging stock consisted of condensibles which resulted from reforming a Mid-Continent heavy naphtha. These data are presented in Table 2.

TABLE 2
Once Through Operation

1. Run No.	1217-1	1217-2	1217-3
2. Pressure #/sq. in. Ga.	800	800	800
3. Temperature, deg. F.	800	800	850
4. Charge, grams per hour	667	635	1327
5. Products			
(a) Liquid, grams per hr.[1]	213	211	546
(b) Gas, grams per hr.	454	424	781
6. Unsaturates Converted, grams per hr.[2]	148	155	307
7. Liquid required from Saturates, grams per hr.	65	56	239
8. Potential liquid from Saturates if Converted to Unsaturates, gr. per hr.	55	46	197

9. Gas Analyses, grams per hr.

	Charge	Product	Charge	Product	Charge	Product
H_2	..	2	..	1	..	2
CH_4	1	6	1	5	2	12
C_2H_4	5	5	4	3	9	4
C_2H_6	19	14	18	17	37	13
C_3H_6	155	92	148	79	309	123
C_3H_8	170	120	162	113	339	161
C_4H_8	172	109	163	109	342	228
C_4H_{10}	85	68	81	71	169	120
C_5H_{10}	41	19	39	8	81	79
C_5H_{12}+	19	19	18	18	39	39

[1] Includes C5+ observed in the product gas which did not appear in the charge gas as such.
[2] 100% conversion to liquids assumed.

Chemical analyses which will detect with certainty saturates to unsaturates juncture are presently impossible or of doubtful accuracy. We are, therefore, forced to the indirect method of observed differences. In this series the liquid product was weighed, and the gases were metered accurately. To penalize to the utmost the idea that saturates directly combined with unsaturates, the latter-named compounds in the feed stock were considered to be polymerized quantitatively to liquids (Table 2, item 6). The difference between these figures and those of item 5(a) denotes the liquid pentane and heavier which must have come from the saturated compounds, either as such or converted to unsaturates and then polymerized. To test this—it has been assumed that when the ethane, propane, and butane disappearing are decomposed thermally to completion, the percent by weight of unsaturates is respectively 93.4, 79.5, and 67.5. These data and the feed compositions permit the calculation of item 8, which represents the potential liquid if the saturates disappearing were converted to unsaturates and polymerized.

It will be noted that in each case the balance of the liquid required, (item 7) could not be produced by polymerization of the potential unsaturates which would be derived from the saturates, and that an appreciable amount of direct combination of saturated with unsaturated compounds must have taken place. Similar observations were made quite independently in experiments conducted in another laboratory in pyrolyzing much less complex mixtures at high pressures and at temperatures between 1000 and 1150°F.

The runs reported in Table 2 were made at 800°F. to 850°F., and at these temperatures one may expect only a slight thermal dissociation of the saturated hydrocarbons—an effect which would, of course, increase with temperature. A succeeding series was run, single-pass, at 1000°, 1050°, 1075° and 1100°F. during which were obtained at 1000°F. results similar to those previously discussed. This was not true at the higher temperatures and in these latter runs it is probable that the saturates were cracking at a sufficiently high rate that liquid formation occurred predominantly through the mechanism of polymerization.

That these results are not confined to operations in which the unsaturate content of the feed stock is high is shown by the results of run 961 (Table 3) in which the net unsaturate content of the charge stock was 13.7 percent.

It will be observed that, as in previous runs, we obtained a liquid yield much in excess of that which would correspond to the unsaturate content of the feed stock—here 425 percent. Obviously, all of the liquid could have been formed from unsaturates produced from saturates, but the character of the naphtha indicated reactions other than simple polymerization.

TABLE 3
Re-cycling Operation

Run No.		961
Temperature, °F.		1,020
Pressure, lb. per sq. in.		1,200
Feed, percent by weight:		
	Gross	Net
C_{2s}	2.5	...
C_3H_6	7.0	4.8
C_3H_8	14.4	10.8
C_4H_8	8.6	8.9
C_4H_{10}	67.5	75.5
Unsaturates, percent by weight		15.6
Net unsaturates, percent by weight		13.7
Net yield, percent by weight		58.2
Net yield as percent of unsaturates in fresh feed		425
Net gallons of liquid per 1000 cu. ft. net gaseous feed		14.29
Percent saturates converted to polymer		55.0

USE OF NATURAL-GAS FEED STOCKS

The refiner who has natural gas available is naturally interested in the yields to be obtained from such charging stocks which will consist substantially of C_3 and C_4 compounds. The results of charging a mixture of 60 percent of C_3H_8 and 40 percent of normal C_4H_{10} indicates what may be expected from feed stocks of natural-gas origin. These data are given in Table 4.

COMMERCIAL OPERATIONS

The practicality of the operation discussed above has been fully demonstrated by the polymerization unit at the Alamo refinery of Phillips Petroleum Company at Borger, Texas, which has been in commercial operation for an extended period of time. The operating schedule between clean-outs varies from 50 to 60 days. The feed stock has consisted largely of butanes; and, due to local conditions, complete re-cycling to ultimate yield has not been practiced. The yields, therefore, are not representative of a unitary process. The quality of the product, however, compares very favorably with that produced on the pilot plant when processing more varied mixtures.

The feed composition which a unitary process plant may be expected to process may vary from either propane or butane, or any mixture of these, to a complex mixture of C_2, C_3, and C_4, compounds in which the unsaturates amount to as high as 80 percent. The entire plant may be considered to be made of two principal parts: the polymerization unit proper, and the gas and cycle recovery system. The polymerization por-

TABLE 4
Re-cycling Operation

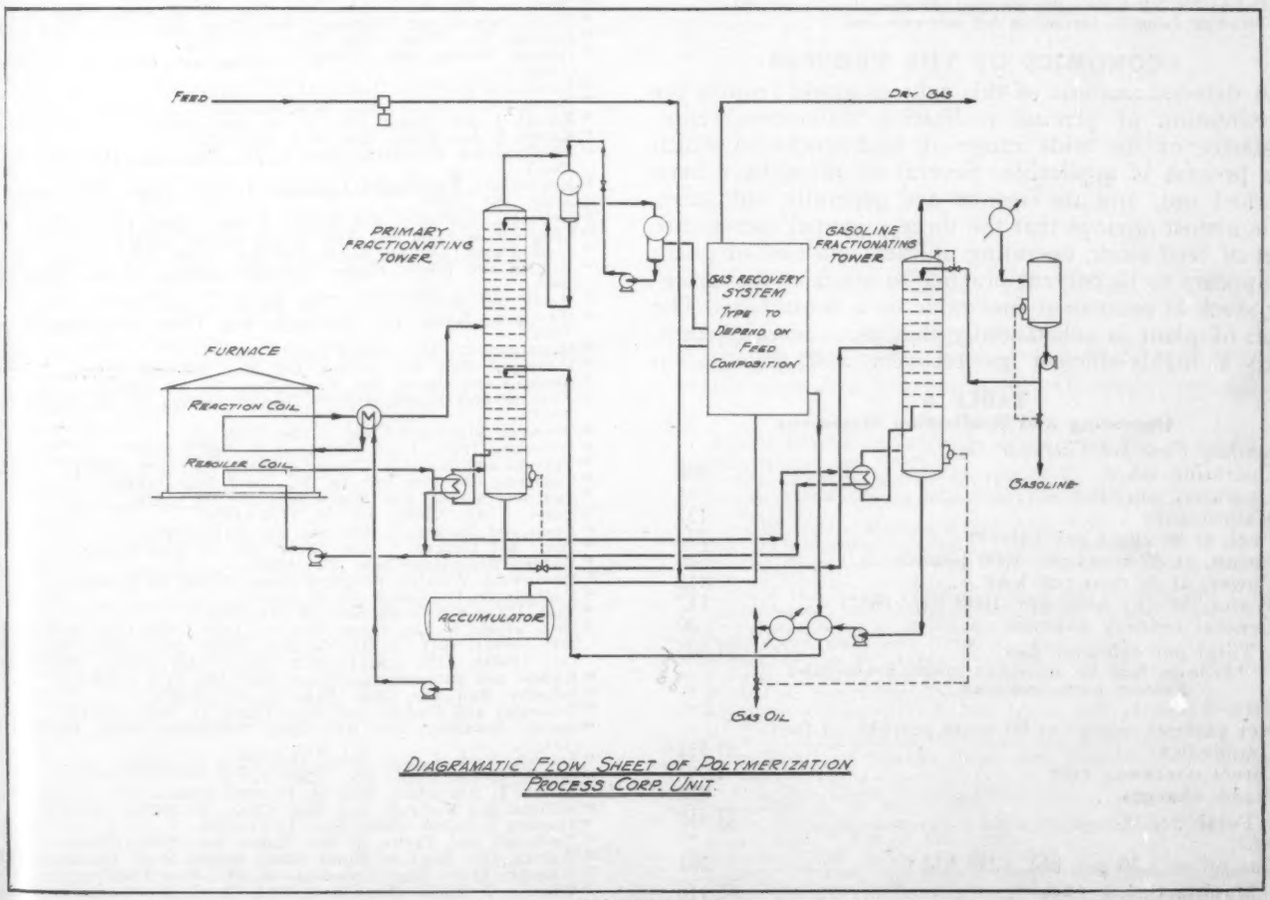
Run No.		1,191
Pressure, lb. per sq. in.		1,200
Temperature, °F.		1,035
Time, sec.		60
Feed composition, percent by weight:		
C_3H_8		58.2
$C_4H_{10}(n)$		41.2
Liquid yield (net), percent by weight		59.0
	Raw Product	Re-run Product
Gravity, °A.P.I.	65.2	64.6
ASTM Distillation in °F.		
Initial boiling point	97	112
5 percent point	116	133
10 percent point	122	137
20 percent point	132	145
30 percent point	143	156
40 percent point	154	164
50 percent point	168	174
60 percent point	183	187
70 percent point	206	203
80 percent point	239	231
90 percent point	325	281
95 percent point	420	306
End point	456	379
C.F.R. motor method, octane No.*	89	93
Reid vapor pressure	10.2	10.0

* Blending value, 50 percent in A-3 reference fuel.

tion of the unit will usually vary with feed-stock composition only to the extent of arrangement of reaction-coil surface. On the other hand, the precise type of gas and cycle-stock recovery system to operate at lowest over-all cost is quite dependent on feed compositions, and, therefore, will vary with this factor. Accordingly, in the typical flow sheet shown in Figure 1 the gas recovery system is not shown in detail. The balance of the plant clearly partakes of the general characteristics of a conventional cracking plant—both as to unit pieces of equipment, materials of construction, instruments, pumps, exchangers, etc. From heat and material balances the fuel consumption will vary between six and 10 percent of the fresh feed stock charged. It should be noted, moreover, that this unitary process can easily be made a part of either a simple gas-oil or reduced-crude combination cracking unit with consequent economies in labor, fuel consumption, etc.

CHARACTERISTICS OF PRODUCT

The characteristics of that part of the product of polymerization which boils in the motor fuel range vary quite widely as functions of feed-stock composition and operating conditions. The use of a feed stock high in unsaturates (65-70 percent by volume) at high conversions to liquid per pass appears to result in a product lower in gravity and paraffin content than does one in which the unsaturates lie between 15 and 35 percent by volume. Aromatics and mono-olefins appear to be predominant in the product from the high unsaturated feed. That material resulting from the unitary-process operation on stabilizer reflux containing 30 to 38 percent by volume of unsaturates will have an A.P.I. gravity of 60-64° when stabilized to a Reid vapor pressure of 10.5 pounds. Its composition is rather paraffinic than olefinic or aromatic, and a considerable portion of the paraffins are *iso*paraffins. It is low in copper-dish gum, and has a very satisfactory induction period. Furthermore, this product is characterized by high volatility. It may be treated without appreciable loss of octane value to low copper dish gum and a stable 30+ Saybolt color, with either clay or a very small amount of acid. The inspections of typical products from processing



DIAGRAMATIC FLOW SHEET OF POLYMERIZATION PROCESS CORP. UNIT

FIGURE 1
Diagramatic Flow Sheet of Polymerization-Process Unit.

various representative feed stocks by the unitary process are given in Table 5.

In Figure 2 are given the distillation curves of two of the stocks shown in Table 6, and for a "blending polymer" reported produced by catalytic polymerization. Figure 3 gives the relation between C.F.R. motor-method octane-blending value and the percent of typical product blended with A-3 reference fuel.

TABLE 5
Pilot-Plant and Commercial-Plant Operation

Charge	Product from Pilot Plant		Product from Commercial Plant
	Stabilizer Reflux (Raw Product)	Stabilizer Reflux (Clay-treated[2])	on Butane Feed (Clay-treated)
Gravity, °API	65.1	66.5	61.4
ASTM Distillation in °F.			
Initial boiling point	100	105	95
5 percent point	117	120	114
10 percent point	123	126	120
20 percent point	134	134	133
30 percent point	146	142	147
40 percent point	156	152	163
50 percent point	164	161	180
60 percent point	178	172	203
70 percent point	195	185	229
80 percent point	227	208	271
90 percent point	296	258	361
95 percent point	377	298	425
End point	414	314	449
C.F.R. motor-method octane No.	...	...	79
C.F.R. motor-method octane No. (Blending Value)[2]	92	90	...
Reid vapor pressure	10.7	...	...
Color	...	30+	30+
Color after 8 hours in the sun	...	30+	...
Copper-dish gum, grams	...	10.4	...
Induction	...	...	120 min.

[1] Cut to 329 EP before clay treating. Treating loss, 1 percent.
[2] Blending value 50 percent in A-3 reference fuel.

ECONOMICS OF THE PROCESS

A detailed analysis of this subject would require the presentation of process realization statements representative of the wide range of feed stocks to which the process is applicable. Several of these have been worked out, and the results are generally indicative. It is almost obvious that the three principal factors are cost of feed stock, operating utilities, and cost of plant. It appears to be current practice to appraise the charging stock at equivalent fuel value on a B.t.u. basis. The type of plant is substantially that of a cracking unit, with a highly-efficient gas-recovery and stabilization system. All of these figures will vary with location. An indicative figure, however, can be given of one specific case. This plant, assumed to be located in the south Mid-Continent area, was designed to handle 25,000,000 cubic feet of refinery gas per stream-day containing 22.3 volume percent unsaturates. The gas was valued at the equivalent of 80 cents per barrel of fuel oil. The value of liquid product other than motor fuel was placed at $1.30 per barrel. A condensed operating and realization statement is appended as Table 6, which shows the over-all operating cost to be 3.5 cents per gallon of gasoline produced.

TABLE 6
Operating and Realization Statement

Operating Cost per Calendar Day:	
Operating labor	$80
Operating supplies	5
Maintenance	137
Fuel, at 80 cents per barrel*	243
Steam, at 30 cents per 1000 pounds	23
Power, at ¾ cent per kwh	412
Water, at one cent per 1000 gal. (85°)	117
General refinery expense	30
Total per calendar day	$1,047
Debit:	
Net gaseous charge at 80 cents per bbl. of fuel equivalent	$1,552
Direct operating cost	1,047
Fixed charges	818
Total	$3,417
Credit:	
Gas oil at 1.30 per bbl. (232 bbl.)	301
Manufacturing cost	$3,116
Net gasoline produced, 2100 bbl. (88,200 gal.)	
Manufacturing cost, per gallon	3.53 cents

*Re-boiler heat for absorption system not included. Refinery waste heat used.

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Fundamental . . . Chemical and Physical Forces in Lubrication

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THIS paper considers the nature of the forces emanating from metal surfaces and from various types of molecules found in and added to lubricants. X-ray diffraction methods are used to study the orientation of polar molecules on metal surfaces, the thickness of such films, the regimentation of polar molecules in lubricating-oil solutions, and the protection of metal surfaces from wear by such adsorbed oriented polar molecules. The work of the authors confirms conclusions from the literature that the extent of the fields of force between metal surfaces and polar lubricants is many times greater than mono-molecular dimensions and approaches, if it does not exceed, the distances between surfaces in viscous lubrication. Highly-polar molecules, such as the esters of chlorinated aliphatic acids and monohydric alcohols, have a powerful effect on the formation of adsorbed films in boundary lubrication and the molecular regimentation in viscous lubrication.

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DURING the past few years more and more attention has been directed by chemists and physicists to the study of lubrication. The former have attempted to determine the relationships existing between the properties of a lubricating oil and its chemical components. The latter have endeavored to elucidate the mechanism of lubrication. Recent investigations have involved the application of chemistry and physics toward the solution of practical lubrication problems.

The chemical and physical forces involved in boundary lubrication have been treated at great length in the literature, but the subject is not yet perfectly understood. While the theory of viscous lubrication, based on hydro-dynamic laws, is well developed, the action of physico-chemical forces in this connection has not been fully realized. This paper will consider the nature of the forces emanating from metal surfaces and from various types of molecules found in and added to lubricants. An understanding of these forces and their profound influence, under both viscous and boundary conditions, is essential to the fundamental theory of lubrication. We propose to control and direct these physico-chemical forces to the improvement of both types of lubrication. For this purpose the addition of certain chlorinated esters of long-chain fatty acids and short-chain monohydric alcohols serves very satisfactorily.

VISCOUS AND BOUNDARY LUBRICATION

Lubricants are applied to the moving parts of machinery to keep the rubbing surfaces from coming into contact and causing high friction or seizure of the metals. In practical lubrication, two distinct types of conditions are encountered. If the rubbing surfaces are completely separated by a comparatively thick film of oil, the lubrication is designated as "viscous." If the lubricating film is extremely attenuated, the type of lubrication is referred to as "boundary," in which case the rubbing surfaces are in approximate contact. The designing engineer aims at perfect viscous lubrication without attaining it, and cannot avoid encountering boundary conditions in the practical use of mechanical devices.

Viscous lubrication is essentially kinetic, and can be realized only when the relative motion of the surfaces is sufficiently great to form a lubricant layer of appreciable thickness between the moving surfaces under suitable conditions of loading, viscosity of oil, temperature, speed and, to some extent, the nature of the oil. When all of these conditions are satisfied, the friction is due almost entirely to the viscosity of the oil and the physico-chemical attractive forces between the rubbing surfaces and the lubricant. Under viscous-lubrication conditions, there can be no metal-to-metal contact; therefore, there should be no wear or seizure of the metal surfaces.

In boundary lubrication, friction is independent of the speed (only within certain limits) and is a function of the load and of the chemical and physical relationships between the rubbing surfaces and between the surfaces and the lubricant. Before passing to a discussion of the physics and chemistry of this state, it may be of interest to note that boundary lubrication must appear in all cases where the speed of rubbing is too low, the oil viscosity is too low, or the load is too great to permit the formation and persistence of a thick layer of lubricant.

In engineering practice, boundary-lubrication conditions may obtain:

1. At the moment of starting a machine from rest.
2. During the extreme slowness of the moving parts just immediately prior to stopping.
3. In reciprocating and rocking motions.
4. With rapid fluctuations of speed or load (shock pressure) which tend to bring the metal surfaces

momentarily within their range of effective attraction.

5. When the original viscosity of the lubricant is too low or is excessively reduced by heat.

6. With an inadequate supply of oil.

OILINESS

Friction is obtained in both viscous and boundary lubrication. Ewing[1] was probably the first to realize the factors contributing to friction in boundary lubrication, and Kingsbury[2 3] considered this concept in his early work.

Many subsequent investigators[4-27] have contributed to our fund of knowledge of the special character of a lubricant which causes differences in the friction when one lubricant is compared to another of the same viscosity under identical conditions. "Oiliness" has been conceived as responsible for the difference in friction.

This definition proposed for oiliness is based upon the historical concept as a friction-reducing property only. There is no known established relationship existing between oiliness, wear, and seizure. It does not appear that the terms "wear" ad "seizure" have yet been satisfactorily defined, or that the elementary factors entering into these phenomena have been systematically investigated. Other things being equal, a lubricant of superior oiliness will develop less heat in use, and to that extent conditions will be favorable for reducing wear and preventing seizure.[23] By controlling the physical and chemical forces involved in lubrication, it is possible to obtain reduced friction (increased oiliness) and also greatly to minimize metal loss from rubbing surfaces by wear or seizure.

Friction between smooth, polished surfaces is caused by the unbalanced forces of molecular attraction acting across the interface. By placing a lubricant between the surfaces, these unbalanced forces are completely neutralized in perfect boundary lubrication; while in perfect viscous lubrication, the rubbing surfaces are separated by the liquid oil beyond their effective fields of force.

POLAR MOLECULES

Molecules of ordinary hydrocarbon lubricants are not sufficiently physico-chemically active to neutralize the unbalanced forces acting at metal surfaces. However, molecules which contain an atom or group of atoms exhibiting secondary or residual valence—which are known as polar molecules—are able to neutralize these unbalanced forces. This is accomplished by means of the polar groups present in the molecules, which are attracted by the forces of the metal surface resulting in a regular orientation of the molecules with respect to the surface. This ability to orient seems to be an inherent property of polar molecules given the proper conditions of molecular mobility.

The orienting and adhesive character of polar molecules has been demonstrated by the works of Marcelin,[33] Devaux,[34] Langmuir,[7] Adams,[30] and Woog.[16] They show that, in the spreading of organic liquids on water, strong selective forces reveal themselves in a preferred attraction by the water for quite definite atoms or groups of atoms of the organic liquid. Thus, for example, water exerts an especially strong attraction for terminal hydroxyl, carboxyl, and other oxygen-containing groups in organic compounds. By these specific selective forces of attraction, the surface films of organic molecules are anchored to the water sub-stratum.

The same authors have shown entirely analogous relationships in the spreading of liquids on solid surfaces. It has been shown, for example, that the carboxyl group displays an especially strong attraction for metal surfaces. In order to prevent metal-to-metal contact in lubrication, the film must be so firmly bound to the rubbing surfaces that it withstands the action of pressure and shearing forces which seek to crush, tear, or squeeze out the film. By virtue of their active polar groups, certain molecules are not only concentrated at the boundary surface, but are also fixed there by strong forces. This adhesivity of the polar film and the viscosity of the lubricant are in no way related. Karplus[35] has found that certain non-viscous oils adhere to a definite boundary surface much better than a viscous oil—which has been confirmed by our work.

From the specific nature of the mutually-attractive forces between the lubricant and the metal surface, it follows that the strength of the attraction depends not only on the polarity of the lubricant, but also on the physical and chemical nature of the metal surface. The polarity of the lubricant, and the kind and strength of the specific forces of attraction emanating from the metal surface, determine the stability of the adhering film. Long-chain polar molecules are firmly rooted with their polar ends on the rubbing surface, with their free ends projecting into the lubricant layer and their chains parallel.

FILM CHARACTERISTICS

Many have assumed that the effective sphere of action of polar molecules is always very small; i.e., that the mutual attraction of these molecules can act only through small distances. The work of Freundlich and others has made the existence of far-reaching forces of attraction appear plausible. The work of Hardy,[10] and his co-workers, on adhesion has proved with certainty that forces of attraction, extending actually through an unexpectedly large circle of action approximating 20,000 Angstrom units (A. U.), emanate from solid boundary surfaces. Kingsbury found that the hydrodynamic laws of viscous lubrication apply to a film as thin as 6,250 A.U. (vide Hersey[23]). The molecular forces of attraction which originate in the solid boundary surfaces are thus not limited to the layer in direct contact with the metal, but are extended far into the interior of the lubricant layer. Trillat[19] has found such powerful fields of attraction between metals and polar compounds that laminated structures of 400-500 molecular layers are formed, which in the case of long-chain fatty acids would give a film thickness of 9,000 A. U. or more. Tausz and Szekely,[22] by capacitance methods, have shown films of 12,000-A.-U. thickness with non-polar compounds which ruptured under stress, but polar films as low as 1,100-A.-U. thickness which did not rupture under the same conditions. Therefore, it is seen that three independent investigators have found film thicknesses of comparable magnitude.

Karplus[35] concluded that the forces of attraction act between the metal surface and the polar groups in the lubricant to form an oriented film, as represented in Figure 1, and to determine the resistance to separation of the adhering film from the metal

surface. The forces of attraction which bind the hydrocarbon chains to each other (as will be discussed later in connection with Figure 1-B), in terms of the work necessary to separate them, were calculated from the approximate molar-cohesion values of Meyer[38]—and amount, for example, of about 17,000 calories for an unsubstituted fatty acid of 18 carbon atoms. These forces of attraction are determining factors for the pressure stability of the film, i.e., for the resistance which the lubricant layer sets up against the forces acting perpendicularly to the solid boundary surfaces. The work necessary to separate the carboxyl planes amounts to about 9,000 calories per gram-mole for unsubstituted fatty acids, and more in acids in which hydrogen close to the carboxyl group has been substituted by strongly polar atoms or groups of atoms. To overcome the forces in the cleavage or methyl plane requires only about 1,790 calories per gram-mole. This explains the outstanding sliding capacity of the lubricant along the cleavage plane.

PHYSICO-CHEMICAL FORCES IN VISCOUS LUBRICATION

Herschel[41] has emphasized the influence of the oil, and particularly of the bearing metal, on the coefficient of friction. He shows that this is a joint property of the oil and the metal forming the rubbing surfaces.

Becker[27] recognized the early interest in surface action between lubricants and metals as it pertains to boundary lubrication, and stated that the influence of surface forces is also of vital importance in viscous lubrication. He concluded: "Thus the thickness of film developed in a bearing depends upon the speed, load, viscosity of the lubricant at the working temperature, and upon four constants— the latter being dependent upon the oil and the bearing surfaces used. In other words, surface action plays a very important part in the development of viscous lubrication . . . . These experiments demonstrate, therefore, that the thickness of oil film developed in a given bearing under definite operating conditions depends on surface action as well as viscosity."

Gilson[36] shows that the kind of metal in the rubbing surfaces has a strong influence on the coefficient of friction. His work was done with a set of bearings operated under conditions to give as nearly perfect viscous lubrication as is possible to obtain. Viscous lubrication was obtained in these experiments by a speed of 2,000 r.p.m., a load of only 10 pounds per square inch of projected bearing area,

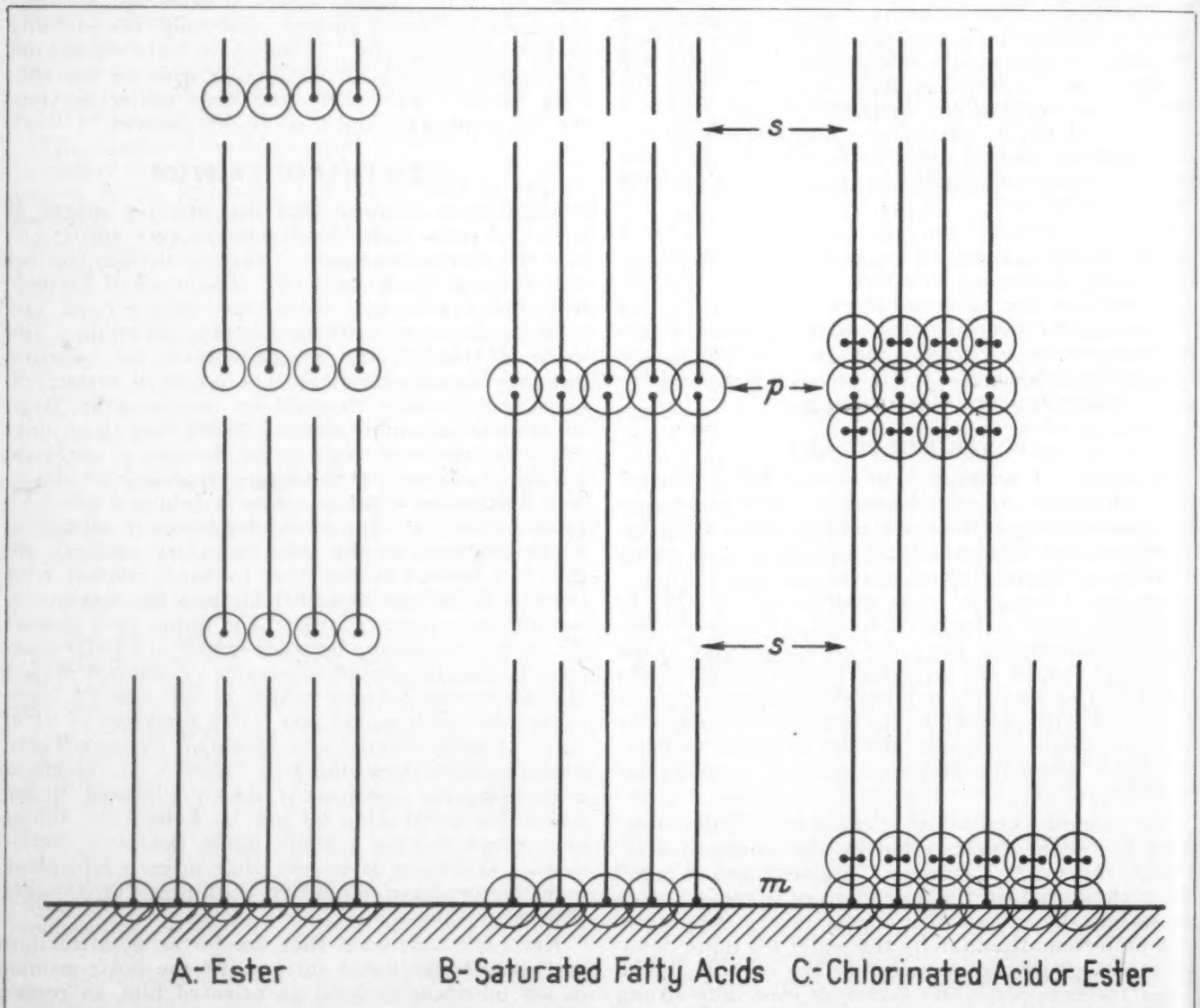


FIGURE 1

and an abundant oil supply. All variable factors, except composition of bearing surfaces, were kept constant. Varying the composition of metal surfaces gave differences in coefficient of friction of 53 percent. This is contrary to the hydrodynamic theory of viscous lubrication, which says that under constant load and speed the only factor affecting the coefficient of friction is the viscosity, i.e., that the coefficient of friction should always be entirely independent of the kind of metal in bearing surfaces.

Since the coefficient of friction in viscous lubrication does vary with the type of metal in the rubbing surfaces, the magnitude of the fields of force around the metal surface must play an important part. Obviously, ordinary non-polar lubricants do not saturate these fields of force to allow a constant coefficient of friction with constant viscosity. We find that strongly-polar compounds in a lubricant, such as the chlorinated esters, do neutralize these fields of force. Furthermore, the X-ray evidence presented later will show that such polar compounds as the chlorinated esters actually produce a more or less complete regimentation of the molecules in the liquid body of the lubricant between the rubbing surfaces. This regimentation, or "cybotaxis," is sufficiently strong that the disturbing influence of temperature increase—which tends toward a chaotic molecular arrangement—has little or no effect for reasonable increments of temperature. This arrangement gives the cleavage planes which promote sliding and, thus, tend to reduce friction.

The neutralization of the fields of force of rubbing surfaces by polar molecules and the regimentation of the molecules in the liquid lubricant may explain, in part, the above anomalous coefficients of friction in viscous lubrication.

The physico-chemical activity at the rubbing surface in boundary lubrication, and in the liquid body in viscous lubrication, may be different in degree, but not in kind. This particular phase of viscous lubrication is being further investigated.

PHYSICO-CHEMICAL FORCES IN BOUNDARY LUBRICATION

As there is no simple and direct method of measuring the physico-chemical forces under conditions of boundary lubrication, many devices and methods have been developed to study the effects of such forces. Probably the most commonly used are the various methods of determining the coefficient of friction under boundary conditions. These measures the oiliness of lubricants and, therefore, give methods of directly comparing film-forming properties of polar compounds in lubricants.

Oiliness can be measured in any device capable of being loaded to thin-film conditions and equipped to measure friction or resistance to motion. Friction is measured under two conditions: "static," which is the resistance to starting of stationary surfaces; and "kinetic," which is the resistance to motion of moving surfaces.

Hardy's[10] method for static coefficient of friction, with its slider and inclined plane which can be set at varying angles, has been widely used by investigators. Table 1 shows some of our results by this method. The value given for each series is an average of 30 tests. The plane and balls were thoroughly cleaned with petroleum ether and alcohol between each series of determinations shown in the table. The check determinations shown in the first part of the table were made without changing the contact surfaces, but the surfaces were changed between each check shown in the second part of the table. Our experience has shown that the degree of polish and cleanliness of the bearing surface has a great influence on the results.

The Almen machine[40] may be used to obtain the static coefficient of friction by determining the "break-away" torque or the force required to start rotation. Table 2 compares the static coefficient of friction as determined with the Almen machine (steel-to-steel) for an SAE-30 mineral oil, and the same product blended with 0.75 percent methyldichlorostearate and with 0.5 percent oleic acid, respectively.

TABLE 1
Static Coefficient of Friction by Inclined Plane

Series	ADDITION AGENT	Average Coefficient of Friction	Decrease (Percent)
	Without Changing Surfaces for Check Tests:		
1	None (mineral oil)	0.255	....
2	1-percent chlorinated ester	0.226	11.4
3	0.5-percent oleic acid	0.207	18.8
	Changing Surfaces for Check Tests:		
4	None (mineral oil)	0.275	....
5	1-percent chlorinated ester	0.246	10.5
6	0.5-percent oleic acid	0.209	24.0

TABLE 2
Static Coefficient of Friction with Almen Machine

	Coefficient of Friction	Decrease (Percent)
Mineral oil, SAE-30	0.215	..
Oil plus 0.75-percent chlorinated ester	0.194	10
Oil plus 0.5-percent oleic acid	0.200	7

We have found a simple modification of the Almen machine to be of value in the chemical laboratory in showing the relative oiliness of various compounds. This hand-operated device uses a steel split bushing and a brass pin as rubbing surfaces and a spring-loaded torque scale. Under a load of 3,000 pounds per square inch of projected bearing area, the starting torque with a mineral oil and with a given compound in the same oil is determined. The reduction of the torque of the mineral oil by a number of compounds compared with their Timken film strength is given in Table 3.

TABLE 3
Effect of Polar Compounds on Starting Torque

No.	COMPOUND ADDED	Timken Film Strength (Pounds)	Decrease in Torque (Percent)
1	Trichlororesorcinol	125.0	74.1
2	Methyldichlorostearate	28.0	60.9
3	Chlorostearic acid	64.0	20.0
4	Ethyldichlorophthalate	38.0	24.0
5	Trichloroanisole	13.8	30.4
6	Oleic acid	10.3	33.3
7	Hexyl chloride	8.8	4.5*
8	o-Chlorophenetole	14.8	8.0*

* Increase.

From the table it will be noted that there is no direct relationship between film strength and oiliness as measured by starting torque. The presence of an element such as chlorine in the molecule does not

necessarily decrease the torque. Since the torque varies with the load and metals used, this test is of value to indicate trends rather than absolute values.

MEASUREMENT OF KINETIC COEFFICIENT OF FRICTION

The measurement of the kinetic coefficient of friction may be determined on the Herschel machine.[41] Table 4 gives the coefficient of friction between steel

TABLE 4
Effect of Metal on the Kinetic Coefficient of Friction

Bearing Surfaces—Steel on:	COEFFICIENT OF FRICTION		
	Mineral Oil	Oil With 0.5 Percent Oleic Acid	Decrease (Percent)
Tin babbitt	0.150	0.101	33
Cadmium lead	0.097	0.110	11*
High lead	0.162	0.094	42
Phosphor bronze	0.173	0.176	2*
Copper lead (1)	0.136	0.126	7
Copper lead (2)	0.154	0 145	6
No. 1 ASTM	0.180	0.140	22
Bronze	0.182	0.123	31
Cast iron	0.133	0.122	8

* Increase.

and various metals when using an SAE-30 mineral oil and the same oil blended with 0.5-percent oleic acid. It will be seen that there is a wide difference in the coefficient of friction obtained by the polar oleic acid on the different metals.

The Almen machine may also be used for measuring the kinetic of coefficient of friction. Table 5 gives the effect of the load in pounds per square inch of

TABLE 5
Effect of Load on the Kinetic Coefficient of Friction

LOAD (Lbs. per Sq. In.)	COEFFICIENT OF FRICTION		
	Mineral Oil	Oil With 0.75 Percent Chlorinated Ester	Decrease (Percent)
1,000	0.269	0.153	43
2,000	0.288	0.135	53
4,000	0.259	0.134	50
6,000	0.243	0.128	47
8,000	0.240	0.125	48
10,000	Seized	0.124	..

projected area for mineral oil, and the same oil containing 0.75 percent of methyldichlorostearate with steel-to-bronze surfaces at 1.2 r.p.m. It will be seen that the coefficient decreases slightly with the inincrease in load. Table 6 shows the results obtained

TABLE 6
Effect of Speed on the Kinetic Coefficient of Friction

	COEFFICIENT OF FRICTION		
Speed, r.p.m.	0.5	600	1,800
Load—1,000 pounds:			
Mineral oil	0.230	0.241	0.289
Oil with 0.75-percent chlorinated ester	0.192	0.192	0.249
Load—5,000 pounds:			
Mineral oil	0.269	Seized	Seized
Oil with 0.75-percent chlorinated ester	0.207	0.162	0.085

by variable speed. The increase in the coefficient of friction with speed under the 1,000-pound load indicates viscous lubrication. The decrease in the coefficient of friction with speed under the 5,000-pound load shows the effect of the polar film under conditions of boundary lubrication.

INTERFACIAL TENSION

Another method of studying the physical and chemical forces in lubrication involves the measurement of interfacial tension between the lubricant and either a metal or water. This may be measured in a number of ways. For example, we employed a drop-weight method for determining interfacial tension between mercury and an SAE-30 mineral oil and the same oil with certain polar addition agents. The capillary was constructed to deliver five drops of mercury each three minutes. Check determinations were hard to obtain until the proper technique was developed. The total weight of 100 drops was used to determine the average weight of one droplet. The difference in density of oil and mercury is so great, compared to slight changes in the oil density due to the incorporation of the polar compound, that this variation may be neglected. Table 7 shows the re-

TABLE 7
Interfacial Tension of Mercury Against Oil by Drop-Weight Method

	Weight of Droplet of Mercury (Grams)
Oil with 5 Percent of:	
Mineral oil	0.206
Trichloronaphthalene	0.192
Trichlorophenol	0.191
Oleic acid	0.190
Monochlorodiphenylene oxide	0.186
Methyldichlorostearate	0.186

sults obtained. The decrease in the average drop weight corresponds to a similar decrease in interfacial tension between the oils and mercury.

The interfacial tension between mercury and the various blended oils, even though in favor of the use of addition agents, does not give a complete picture. Different results would be obtained with the same oil blends on other metals because of the differences in the nature and magnitude of the fields of force at the surface of various metals. Since the other metals are not liquid at reasonable working temperatures, this method cannot be employed—and is, therefore, of little practical value.

CAPACITANCE METHOD

Tausz and Szekely[22] determined, by capacitance methods, the thinnest film which is stable under certain conditions. Since the imperfections of two highly-polished flat metal surfaces prevent uniform separation by a lubricant layer, they used a cleaned, oiled steel ball immersed in clean mercury. They found that very tough thin films could be obtained with polar vegetable oils and lubricants. For example, the films of non-polar oils of less than 5,000 A.U. would break in two days, while polar oil films 300-1,000 A.U. in thickness were very resistant and did not break under equal stress for 65 days. The results show that the force with which lubricants are attached to metal surfaces depends on the type of polar molecules present. A good lubricant should contain compounds with such properties, although all polar molecules are not satisfactory as addition agents.

OIL ADHESION

Parrish and Cammen[42] define "oiliness" as "adhesion"; and claim that their "Adher-O-Scope," by measuring the amount of oil adhering to a metal

drum after rotation at high speed, is a measure of this characteristic. Since some metals are permeable by oil as shown by Gill,[43] the Sperry-Cammen tester would not distinguish between the polar affinity of molecular layers and simple absorption of the oil by the metal.

HEAT OF WETTING

When certain polar liquids are brought into contact with metals, the neutralization of the mutual attraction between the polar molecules and the metal-surface molecules usually results in the evolution of heat. The total heat of wetting is dependent on the total metal surface. Since a solid metal surface does not have sufficient area to give a measurable heat of wetting, a powdered metal is used. The surface area is difficult to determine with any degree of accuracy when a powder is used; hence the data indicate only the relative forces with which the polar molecules attach themselves to metal.

The heat of wetting has been employed to compare the lubricating efficiency of different lubricants. Assuming that this characteristic is a measure of the adhesivity of the lubricant for the metal surface and that no chemical action takes place, then the best lubricants should have the highest heat of wetting. While it would be possible to have a negative value with a positive free energy of wetting, as a rule the heat of wetting runs roughly parallel with the adhesivity—just as the heat of chemical reaction often runs parallel with chemical affinity.

Bachmann and Brieger[31] studied the heat of wetting obtained by treating certain lubricants with freshly-prepared copper powder. Following their technique, we obtained data on additional substances which are shown in Table 8. The heat of wetting is reported as the number of calories produced per 100

TABLE 8
Heat of Wetting of Oils on Powdered Copper

POLAR COMPOUND IN OIL	HEAT OF WETTING IN CALORIES	
	Bachmann and Brieger	Authors
Mineral oil	3.8	2.8
Oleic acid	22.0	36.0
Castor oil	12.4	....
Linseed oil	14.4	....
Methyldichlorostearate	....	12.8

grams of copper for each percent of the polar compound in the oil, when a sufficient quantity is employed for wetting. Lubricants containing polar compounds show a higher heat of wetting than refined straight-hydrocarbon lubricants.

All the above methods of investigation pertaining to the effect of physico-chemical forces between polar molecules and metals have contributed to our general knowledge of film lubrication. These methods of test do not give any information whatever concerning the structure and dimensions of the oriented film. We have used X-rays for the study of these films and their characteristics.

X-RAY INVESTIGATIONS OF EFFECTS OF PHYSICO-CHEMICAL FORCES IN LUBRICATION

The early use of X-rays in studying the characteristics of fatty-acid films on metal surfaces led us to the consideration of X-rays for the general study of polar compounds in viscous and boundary lubrication. We found it necessary to develop new methods and new technique of applying X-rays to the problem. These new developments will be reported by the authors elsewhere.

Bragg,[14] Trillat,[19] and Mueller and Shearer[37] observed from X-ray patterns the peculiar properties of fatty-acid films which could be used to account for their beneficial properties when added to a mineral oil. Trillat proved, by making X-ray photographs of fatty acids adsorbed on metal plates, that polar compounds orient directly and spontaneously on metal surfaces.

FUNDAMENTAL CONCEPTS

In the interpretation of X-ray photographs certain fundamental concepts must be kept in mind. Some polar molecules orient so systematically that their thin-film structure is quite regular—and the entire film behaves as a diffraction grating in the same sense as any single crystal. By analogy with the X-ray study of crystals, similar studies have demonstrated that these polar molecules orient themselves in definite fashion side by side. The long-chain polar molecules also orient in an end-to-end fashion, the degree of which is measured by the number and shortness of the diffraction arcs. This may be illustrated by a stack of carpets, each carpet representing a parallel plane and the pile of the carpet representing the molecules standing perpendicularly to these planes.

A schematic portrayal of the molecules in the film is shown in Figure 1. The vertical lines represent the hydrocarbon chains; the dots at the end of the lines, the polar groups. The circles are used to designate the interlocking fields of force. In the primary film the polar groups are directed toward, and firmly attached to, the metal surface, **m**, by virtue of their marked affinity for it. The hydrocarbon chains are arranged parallel to one another. When a first layer has been formed on the metal surface, a more or less homogeneous surface is produced by the free ends of the adsorbed molecules, which serves as a foundation for the formation of a second layer of attracted polar molecules. In this way many layers of adsorbed molecules may be formed on a metal surface, although the force which serves to bind the molecular layers decreases progressively as the distance from the surface increases. The polar groups standing opposite each other are bound firmly in consequence of their strong affinity. In the planes of the methyl groups the mutual forces of attraction, as previously shown, are very slight on account of the small affinity between these groups. In these planes, therefore, sliding can result with minimum friction.

The polar compound may act in a number of different ways in building this film. Figure 1-**A** shows how a long-chain weakly-polar compound, such as methylstearate, builds a film with the polar end of the first layer of molecules attached to the metal surface and all the single molecules in the succeeding layers oriented in the same direction. Molecules of fatty acids, such as stearic acid, orient as shown in Figure 1-**B**, with the first layer arranged monomolecularly on the metal surface like methylstearate. The succeeeding layers are built with a double molecular unit, which is formed by the association of two molecules because of the high polarity of the carboxyl groups. These molecular arrangements are referred to as single and double, respectively.

The type of film formed by chlorinated esters is shown in Figure 1-**C**. The circles on each of the

hydrocarbon chains near the the carboxyl end represent the fields of force of the two chlorine atoms on the alpha carbon. These fields of force magnify the total degree of polarity of the molecule. By the introduction of the two chlorine atoms, the weakly-polar methylstearate becomes more active physico-chemically than the stearic acid, and displays a double molecular arrangement similar to stearic acid.

If the chlorine atoms are placed on the chain near the middle, they detract from the fields of force around the carboxyl group—and cause the molecule to act quite differently. Probably in this case the long-chain molecule is weakly attached to the metal surface at the carboxyl end at the point of chlorine introduction, rather than strongly at the carboxyl end only.

The planes, **s**, shown in Figure 1-**B** and 1-**C** are the slippage planes which are not present in Figure 1-**A**—because, with the single-molecular arrangement, there is no plane in which the methyl ends of the molecule are in contact. The planes, **p**, have the maximum electron-density concentration, and are the diffraction planes for the X-ray beam.

X-RAY DIFFRACTION

The diffraction of an X-ray beam by oriented adsorbed layers on a metal surface is shown diagrammatically in Figure 2. The planes of diffraction, **p**,

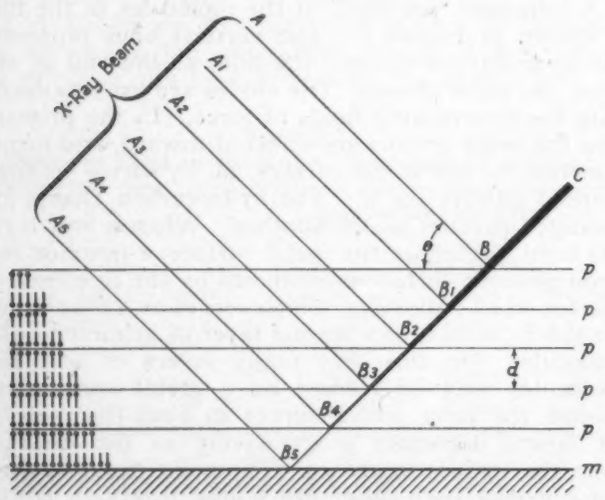


FIGURE 2

are the planes of maximum electron density as shown in Figure 1. If a monochromatic X-ray beam is passed through the film at the angle θ to the diffraction planes, **p**, the elements of the beam **A-A**$_5$ will be in phase at the points of diffraction **B-B**$_5$, and will combine to form the diffracted beam, **C**. If there is a sufficient number of molecular layers, the diffracted beam will be built up to sufficient intensity—as indicated by the broadening of the beam to affect a photographic plate placed perpendicularly to the beam.

The relationship between the factors affecting the diffraction of the X-ray beam are given in the fundamental formula:

$$n\,\lambda = 2d\,\sin\,\theta$$

in which n represents the number of the order of diffraction, λ the wave length, d the distance between the diffracting planes, and θ the angle of incidence.

If an X-ray diffraction photograph be taken of a crystal in which the molecules are arranged in a perfectly orderly fashion in all three dimensions, the result is a geometrically-arranged series of sharply-defined spots of light. The example given in Figure

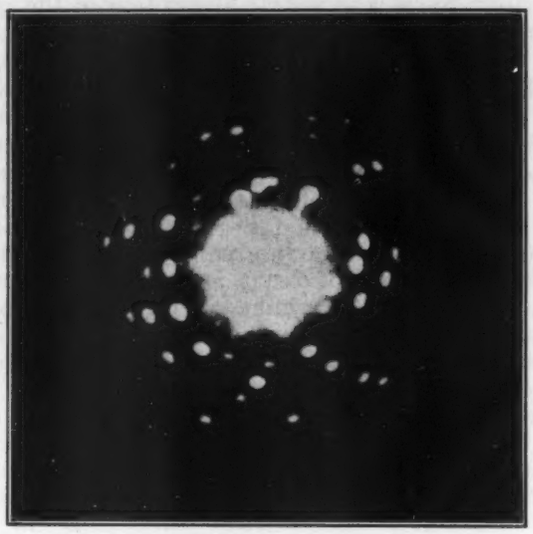


FIGURE 3

3 is the diffraction picture of an iron crystal, and shows the perfect pattern resulting from complete molecular arrangement or regimentation.

On the other hand, if an X-ray photograph be taken of material in which the molecules are of varying sizes and shapes and the arrangement is random, the result is a diffused halo, as shown for a hydro-

FIGURE 4

carbon lubricating oil in Figure 4. No diffraction lines or spots are to be found, and no orderly molecular arrangement is indicated.

It will be realized that any intermediate stage between perfect molecular regimentation as shown by a crystal (Figure 3) and complete random arrangement, as in Figure 4, may be obtained—depending upon the relative degree of molecular arrangement. Figure 5 is a typical diffraction photograph showing partial orientation. The more complete the molecular arrangement, the shorter and sharper are the arcs. The greater the number of molecular layers in the oriented film, the greater the number of orders of diffraction obtained.

POLAR-FILM THICKNESS OF PURE COMPOUNDS

By our study of X-ray photographs it has been found that a number of oxygen- and chlorine-containing compounds give extraordinarily well-oriented films on metal surfaces. In some cases, as previously shown, the thickness of the layers corresponds to twice the length of the molecules; or, in other words, each building unit consists of a pair of molecules attached end to end, as shown in Figure 1-**C**. Table 9 shows the thickness of each layer, in A.U., and the type of arrangement of a number of polar compounds. Referring to methylstearate of single-molecular arrangement and methyldichlorostearate of double-molecular arrangement, we find that the molecular length with the double molecules is not as great as two times the single-molecular length. This reduction in length with double-molecular arrangement is probably due to the mutual saturation of fields of force at the polar ends. Our investigation confirms the conclusions of Adams[30] and Gilson[36] that oxygen plays a very important part in the formation of these protective polar films.

It is apparent that, knowing both the thickness of each molecular layer and the number of layers required for each diffraction arc, it would be possible to calculate the thickness of the whole adsorbed film. The thickness of the layers is shown in Table 9. It is now possible to determine the number of molecular layers in the adsorbed film which is required to produce a microphotometrically detectable order on the photographic plate.

TABLE 9
Layer Thickness and Molecular Arrangement of Oriented Films

POLAR COMPOUND	Layer Thickness	Molecular Arrangement
Stearic acid	39.5	Double
Dichlorostearic acid	39.2	Double
Methylstearate	26.5	Single
Methyldichlorostearate	45.0	Double
Methylpalmitate	22.2	Single
Ethyldichlorostearate	51.5	Double
Cetyldichloroacetate	27.6	Single
Octadecyldichlorostearate	42.9	Doubtful

The determination of this factor depends on the technique developed recently by Langmuir and Blodgett[7,8] for the application of mono-molecular films one at a time to a solid surface. As reported by Clark, Sterrett, and Leppla,[39] we used this method to apply known numbers of molecular layers of certain polar materials to various solids. By making X-ray photographs at progressive stages, it was possible to determine the minimum number of layers necessary to produce a microphotometrically detachable order of diffraction on the photographic plate. The minimum for non-metallic polar compounds was found to be from 19 to 45 layers—depending on the type of molecule being adsorbed. For example, Table 10 shows the result of picking up monomolecular layers of stearic acid from pure water on a brass rod. It will be observed that, since 71 molecular layers show only the third order and 125 show the fifth order, approximately 25 molecular layers are required for each diffraction order. The relative intensity of the odd orders is, as a rule, greater than the intensity of the even orders, as shown by the table.

TABLE 10
Orders of Diffraction of Films of Stearic Acid on Brass

No. Molecular Layers	Relative Intensity by Order Number				
	1	2	3	4	5
71	7	0.5	2.5	0	0
125	12	3.0	4.7	0	1

The product of the minimum number of layers and the number of orders appearing gives the minimum number of molecular layers which must have been formed. Since stearic acid shows seven diffraction orders, each requiring approximately 25 mono-molecular layers of 12½ double layers of 39.5-A.-U. thickness (see Table 9), this film must be approximately 3,500 A.U. thick. Upon esterifying stearic acid, the polarity is decreased so that only 3 diffraction orders appear. Therefore, assuming the minimum 19 molecular layers for each diffraction arc, the film thickness with the ester would be only 1,500 A.U. However, on chlorinating the ester, 31 diffraction orders appear. Taking the minimum number of molecular layers required for each order, and assuming that a linear relationship holds for 21 orders, the film thickness of the chlorinated ester is approximately 9,000 A.U. This figure is of enormous magnitude in the field of molecular dimensions, and is in good agreement with early estimates of Hardy[10] and Trillat.[19]

The high orders of diffraction shown by the chlorinated ester are quite interesting, as their appearance indicates an unusually high degree of orientation. From ample data concerning the length of these molecules, we know the arrangement is perpendicular to the metal surface and that the spacings represent the length of the molecules. This fact, coupled with the absence of side spacing, indicates the cross-bonding between the molecules by secondary forces —which stabilizes the oriented molecules. This secondary bonding is obtained, as previously pointed out, by the chlorines on the alpha-carbon atom. The bonding of the polar molecules on the metal surface, and the cross-bonding with the chlorine, is accomplished to such a degree that in some cases X-ray

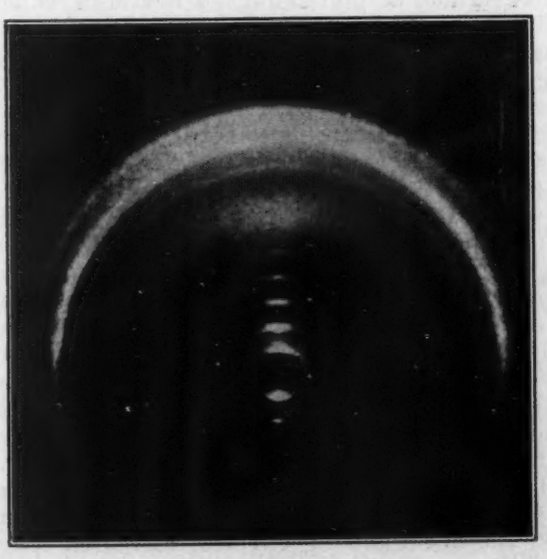


FIGURE 5

patterns indicate a new condensed molecular arrangement near the metal surface.

EFFECT OF METAL SURFACE

Polar compounds will not orient to the same degree on different metals. Table 11 shows the results obtained using pure compounds on various metals. The numbers in the table have reference to

TABLE 11
Orientation of Polar Compounds on Various Metals

SUBSTANCE	Iron	Zinc	Cadmium	Copper
Stearic acid	..	2	3	1
Methylstearate	2	1	1	..
Octadecylchlorostearate	1	2	2	3
Ethyldichlorostearate	1*	2†	2†	..
Monochlorodiphenylene oxide	1	1	1	2
Trichlorophenol	1	1	3	4
Trichloronaphthalene	1	1	1	1

* 21 orders of diffraction present.
† 15 orders.

the relative rating of orientation observed for the particular compound on the series of metals. No comparison is made between the various compounds. The number *1* signifies the best orientation; *2*, the the next best, etc. It will be seen that most of the compounds form their thickest film on iron, and that the chlorinated ester forms extremely thick films on all the metals except copper, as proved by the unusually large number of orders of diffraction shown for ethylidichlorstearate.

In addition to determining the minimum thickness of polar films on metal surfaces, we have determined by study of mono-molecular layers the actual metal-surface area occupied by each polar molecule. Molecules such as methyldichlorostearate cluster together side by side on the metal surface, and are separated by the thickness of the molecule only. The area covered by each of these molecules, with maximum spreading on a surface, has been found to be 20 square A.U.

ORIENTATION IN SOLUTION

We find that polar compounds in dilute hydrocarbon-oil solution, such as is used in practical lubrication, orient on metal surfaces more or less completely as they do in the pure state.

It is not possible to see the total number of orders of diffraction in the case of X-ray photographs of solutions of polar addition agents in mineral lubricating oil, because the diffused halo due to the mineral oil completely masks the outer orders or arcs. We have, however, been able to detect as many as seven distinct orders inside the oil halo when using a dilute solution of chlorinated ester. It is, therefore, evident that bearing surfaces are separated by more than 6,000 A.U. when a chlorinated ester is used in a lubricating oil. Thus, this oriented film is approximately as thick as the previously-proved minimum film thickness for viscous lubrication.

REGIMENTATION IN SOLUTION

The polar molecules in dilute solution not only orient upon the metal surface to a degree approaching perfection, but also arrange themselves in an orderly fashion throughout the mass of the liquid and tend to direct the regimentation of the molecules of the hydrocarbon lubricant. Similar cybotactic regimentation has been amply substantiated by Stewart[44] and by many others.[39 45 46 47]

This characteristic was investigated by studying the effect of the presence of polar compounds upon the crystallization of paraffin wax from oil-wax solution. Wax crystallizes in a randomly-arranged mass of small crystals, giving a partially-oriented diffraction picture in many respects similar to Figure 5. When five percent of a highly-polar compound such as methlydichlorostearate is added to the wax-oil solution, the resultant diffraction pattern is given in Figure 6. The intense short arcs, on both the vertical and horizontal axes, represent substantially perfect orientation and regimentation. The broad diffused oil halos, representing the side spacings of the molecules, have been replaced with short, sharply-defined spots on the horizontal axis. As far as we know, this is the first completely-regimented arrangement reported for the molecules in a hydrocarbon mixture. The polar compounds arrange themselves in a widely-spaced lattice structure, which might be likened to the structure in a honeycomb. This orderly regimentation is such that, when the wax crystallizes from the solution, the lattice structure is impressed upon the wax crystals—which grow or arrange themselves in conformity with the regimentation of the polar molecules.

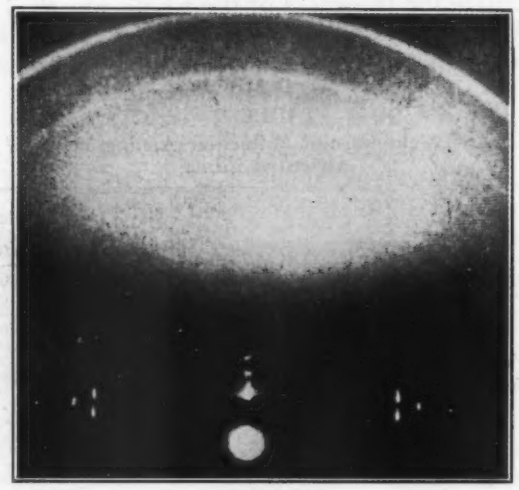


FIGURE 6

REGIMENTATION IN LUBRICATING OIL

The effect of polar compounds upon molecular regimentation in lubricating-oil solutions is not as easily demonstrated as in the case of the wax solutions. The X-ray photograph of a lubricating oil (Figure 4) gives no visible indication of oriented molecular layers. However, the pattern may be investigated by microphotometric analysis, thereby showing the variations of the intensity of the diffracted X-ray beam radially through the oil halo. These variations in the intensity of the halo will be found dependent upon the degree of cybotactic arrangement. Increasing temperature tends to destroy regimentation and produce a more chaotic molecular arrangement. Therefore, if a microphotometer analysis be made at several increasing temperatures, it will be found that the maximum variation in intensity becomes less and the halo broadens and becomes more diffused.

This method, therefore, permits the investigation of the effect of polar molecules in the oil, since the regimentation of a polar compound would tend to resist the disorganizing effect of increased temperature. Figure 7 illustrates the effect of the presence

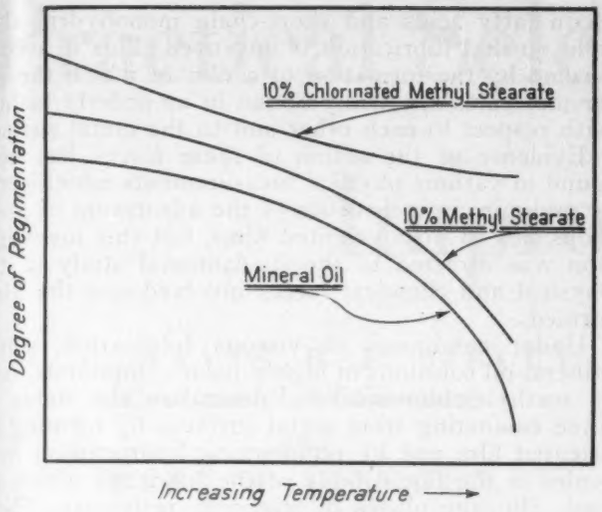


FIGURE 7

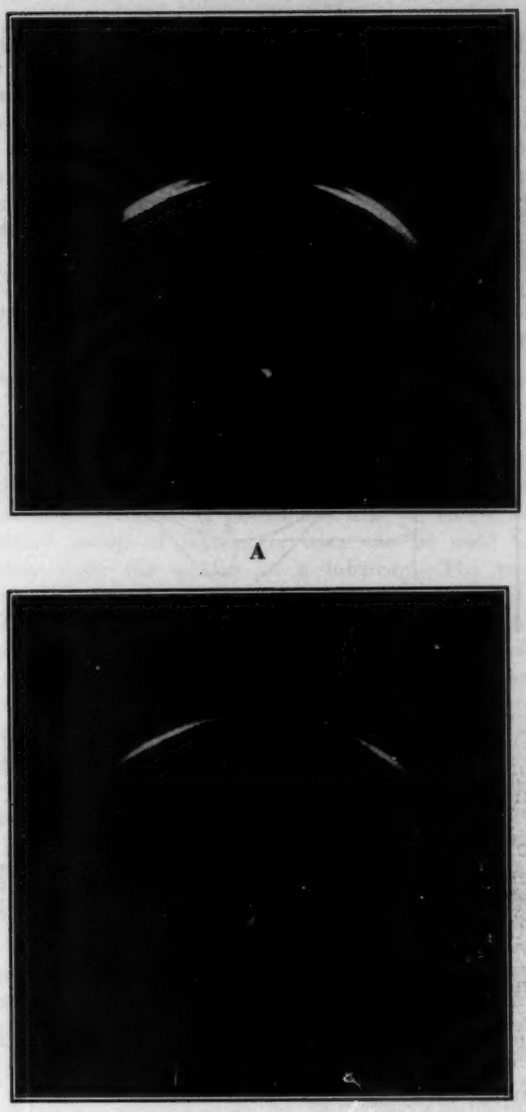
of 10 percent of methylstearate and of methyldichlorostearate on the temperature-regimentation curve. The slopes of the curves show the relative decrease of regimentation with increasing temperatures. The vertical position of the curves is not significant, as the sensitivity of the microphotometer was not the same. From the figure it will be noted that the curves for mineral oil and methylstearate slope downward, showing marked decreases in the degree of regimentation with increasing temperature. The curve for the blend of oil and methyldichlorostearate shows a very small decrease in degree of regimentation, with a curve flattening out at the higher temperatures. This study was conducted through a temperature range up to approximately 250° C. Further investigations by this method disclosed that the amount of regimentation is directly proportional to the concentration of the methyldichlorostearate.

We may conclude from these examinations that molecules of chlorinated esters are highly regimented in the liquid state by their strong bonding force. These bonding forces of the polar molecules affect the oil molecules by reducing their tendency toward more random arrangements with temperature increases.

METAL-FIBER PROTECTION AS A MEASURE OF LUBRICATING ABILITY

Many types of laboratory and field tests have been employed to prove that a film of the polar compound is beneficial in lubrication. Davis, Lincoln, and Sibley (in the paper which follows this on the program) will describe tests which demonstrate that the film of polar compound protects the metal surface from corrosion and wear. By X-ray technique we have found that certain polar compounds in a lubricant will protect rubbing surfaces. Our experiments were based on the crystalline arrangement at the surface of worked metals.

In forming metals into desired shapes by drawing, stresses are applied which serve to arrange the surface metallic crystals with a preferred orientation which may be termed "fibering," because of the resemblance of the X-ray pictures of these surfaces to those of natural fibers. If a metal showing such fibering is reworked so that the direction of stress is at right angles to the original stress, the first set of fibers will tend to disappear. The macroscopic



A

B

FIGURE 8

directional striations, sometimes visible on the surface of metals due to working, are not susceptible to X-ray examinations as are the effects due to crystalline arrangement.

The changes in crystal structure due to working were utilized in determining the value of polar compounds in lubricants for protecting metal surfaces and preventing wear and, hence, their lubricating value. A drawn brass rod, showing suitable fibering in a direction parallel to its axis, was made into Almen pins. After X-ray photographs had been made of these pins to measure the degree of original crystal orientation, they were run for five minutes in the Almen machine with various lubricants, using a load of 2,000 pounds per square inch of projected bearing area and a speed of 600 r.p.m. This load was selected because it is not great enough to destroy completely the surface fiber structure during the test period when a satisfactory polar compound is included in the lubricant. Photographs of the pin surfaces, after the test, were made and compared with the first photographs.

Figure 8-**A** shows a typical picture of the fiber structure before use, while Figure 8-**B** gives the result on the same pin after use. In Figure 8-**A** the difference in intensity of the metal-diffraction lines

between the maximum and minimum points is readily seen, while in Figure 8-**B** it will be noticed that the variation in intensity is much less. While the differences in intensity of different parts of a metal halo are apparent to the eye in cases such as are represented in Figure 8-**A** and 8-**B**, they are more often sufficiently difficult to discern so that advantage must be taken of a microphotometer to discover these variations in intensity. By measuring in this way the intensity of the light at various points along a halo, one may plot intensity against distance—obtaining curves such as shown in Figure 9.

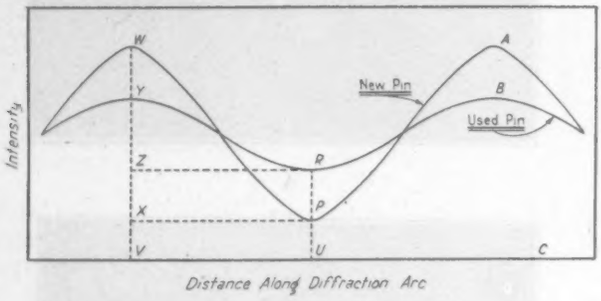


FIGURE 9

Curve **WPA** represents the intensities around one semi-circular line of the X-ray pattern of the new Almen pin (see Figure 8-**A**) and curve **YBR** shows the same for the used Almen pin (see Figure 8-**B**). The peak height of the curves compared with an adjacent point of minimum intensity is directly proportional to the number of metal crystals having that particular orientation.

Hence $\frac{YZ}{WX} \times 100$ gives the percentage of fibered structure remaining on the surface of the metal after the test.

In this way the data on the various blends shown in Table 12 were obtained. It is apparent from the

TABLE 12
Metal-Surface Protection by Blended Lubricants

	Unit Load (Lbs. Per Sq. In.)	Fiber Remaining (Percent)	Timken Film Strength (Pounds)
Oil with One Percent of:			
Mineral oil	2,000	0	8.8
Mineral oil	1,000	0	...
Dichlorostearic acid	2,000	37	38.5
Methyldichlorostearate	2,000	47	28.0
Chlorodiphenylene oxide	2,000	40	28.0
Chlorodiphenyl	2,000	0	25.5

table that, using a straight mineral oil and a load of only 1000 pounds per square inch, the fibering was completely destroyed. Additions of one percent methyldichlorostearate to the mineral oil gave excellent protection of the surface, as shown by the fact that after the test 47 percent of the original surface fibering remained unchanged at two times the load.

SUMMARY

The physico-chemical forces emanating from metal surfaces and from certain types of molecules, known as polar molecules, profoundly affect the behavior of the metals and lubricants involved in boundary lubrication, and are of importance in viscous lubrication. The attractive forces between metal surfaces bearing one on another are neutralized by strongly-polar molecules, such as chlorinated esters of long-chain fatty acids and short-chain monohydric alcohols, so that lubrication is improved. This is accomplished by the formation of a film in which the polar molecules are firmly bound in an orderly fashion with respect to each other and to the metal surface.

Evidence of the action of these forces has been found in various physical measurements which serve as preliminary indications of the adsorption of polar molecules to form oriented films, but this investigation was directed to the fundamental study of the physical and chemical forces involved and the films formed.

Under conditions of viscous lubrication, dilute mineral-oil solutions of highly-polar compounds, such as methyldichlorostearate, neutralize the fields of force emanating from metal surfaces by forming an oriented film and by regimenting hydrocarbon molecules in the liquid body of the lubricant which affords slippage planes of minimum resistance. These actions of the polar films are of importance in explaining the anomalous coefficients of friction in viscous lubrication. X-ray investigation of adsorbed film structures of pure compounds shows that the type of molecular building unit, regularity of arrangement, and the number of molecular layers formed depend on the compound and on the metal. The strongly-polar molecules of certain chlorinated esters form adsorbed films on metals of unusual thickness and regularity of arrangement. The thicknesses of these oriented films of strongly-polar compounds on metal surfaces are of enormous magnitude when compared to molecular dimensions. The present results show a film thickness of 9,000 A.U., which serves as a confirmation of Hardy's measurement of 10,000 A.U., Trillat's of 9,000A.U., and Tausz's of 8,500 A.U.

In order to demonstrate that the orienting ability of the pure polar compounds is also effective in dilute solution, oil-wax mixtures were investigated. In dilute mineral-oil solution, methyldichlorostearate forms films of such thickness that a pair of metal surfaces approaching the limit of viscous lubrication of about 6,000 A.U. are separated by a completely-oriented film of polar molecules.

The stability of the regimented (cybotactic) groups of polar addition agents in lubricating-oil solution is demonstrated by the resistance of methyldichlorostearate blends to the disorganizing effect of temperature increases.

By means of a new method of measuring changes in the surface structure (fibering) of metals, it has been shown that lubricants containing methyldichlorostearate actually protect rubbing metal surfaces from wear.

ACKNOWLEDGMENT

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Practical Selection *of* Improved Lubricants

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THIS paper discusses the increasing need for improved lubricants because of the increased speeds, loads, and temperatures of the modern automotive engine. It points out that no single or limited group of laboratory tests can be used to define fully the quality of a lubricant. The two possible methods of improving a lubricant are: 1, the improvement of physical characteristics and stability which may be accomplished by special refining methods; and, 2, the improvement of the actual ability to lubricate and protect metal surfaces under severe lubricating conditions. The accomplishment of the latter by use of carefully-selected addition agents is considered in this paper. Detailed discussion is given of the many factors which must be considered in selecting an addition agent—including load-bearing capacity, oiliness, rate of wear and corrosiveness on bearings and cylinders, oxidation and thermal stability, volatility and toxicity. The final proof of quality must depend upon actual service tests on the road. The results of laboratory and road tests are given to show that all these requirements can be obtained by addition to the lubricant of a small percentage of the ester of a chlorinated aliphatic acid and a monohydric alcohol such as methyl-*a*, *a*-dichlorostearate.

This paper was presented at Sixteenth Annual Meeting, American Petroleum Institute, at Los Angeles, November 13, 1935.

THE problem of selecting an oil in the laboratory for its true lubricating value is as yet unsolved; and, following the thought of an old maxim, the proof of an oil is the lubrication therewith. The physical requirements of a motor lubricant, viz., viscosity, pour test, flash, volatility, etc., are fairly well established and understood. On the other hand, the chemical characteristics — particularly those having to do with *lubricating value* and stability — are largely mysteries. The increase in knowledge of the mechanics of the true lubricating film has been considerable during the past few years, but the general application of that knowledge to practical lubrication has been very slow.

The increasingly severe requirements on a lubricating oil demanded by the modern powerful engine operating at high speeds and temperatures has resulted in the recognition of the need for a better lubricant. This need for a *better* lubricant has been answered in two general ways: improved refining methods to give better physical and stability characteristics, and the use of addition agents to improve those same characteristics as well as to add materially to the true *lubricating value* of the mineral oil.

In several cases these addition agents have been offered after years of research work and ample practical service tests which have proved their worth. In far too many cases, however, "dopes" are being offered to the public for addition to motor oil—which are based on insufficient empirical tests, and are in many cases actually detrimental to the equipment in which they are used.

The Continental Oil Company's theoretical study of the mechanics of lubrication has been given by Clark, Lincoln, and Sterrett. The authors of the present paper will briefly cover the history of the use of addition agents by their company, the factors which must be considered in the selection of an addition agent, and the practical improvements which may be obtained from the use of a proper agent.

HISTORICAL DEVELOPMENT

It has been known for many years that, under severe operating conditions, animal and vegetable oils give better lubrication than petroleum or "mineral" oils. The first step towards an explanation of this phenomenon was the report on the work of Wells and Southcombe given before the Physical Society[1] of London in 1919, and the Society of the Chemical Industry in 1920,[2] in which they showed the improved lubrication to be due to small quantities of free fatty acids adsorbed on the metal surface. They suggested the addition of small amounts of free fatty acid to mineral oils to obtain the oiliness characteristics of fixed oils, and termed this their "germ process."

In 1920 Southcombe[3] gave, before the National Petroleum Association, a paper on the "Germ-Process Theory." Through contacts made at this meeting Continental Oil Company, then Marland Oil Company, acquired the North American rights under the Wells-Southcombe patents,[4] and from 1921 to 1933 marketed blends of oleic acid and mineral oil.

However, it was in time realized that the fatty acids were not ideal addition agents for automotive engine lubrication, and the Continental research organization was assigned the problem of developing improved addition agents. The fatty-acid blends gave exceptionally high oiliness characteristics of low friction

under boundary-lubrication conditions, and under those conditions fully protected the bearing metal from excessive wear. They maintained lubrication under severe operating conditions or lack of sufficient oil for longer periods than could a mineral oil. While they did not have the ability to increase the load-carrying capacity, that factor was of relatively little importance in automotive lubrication until the past two years.

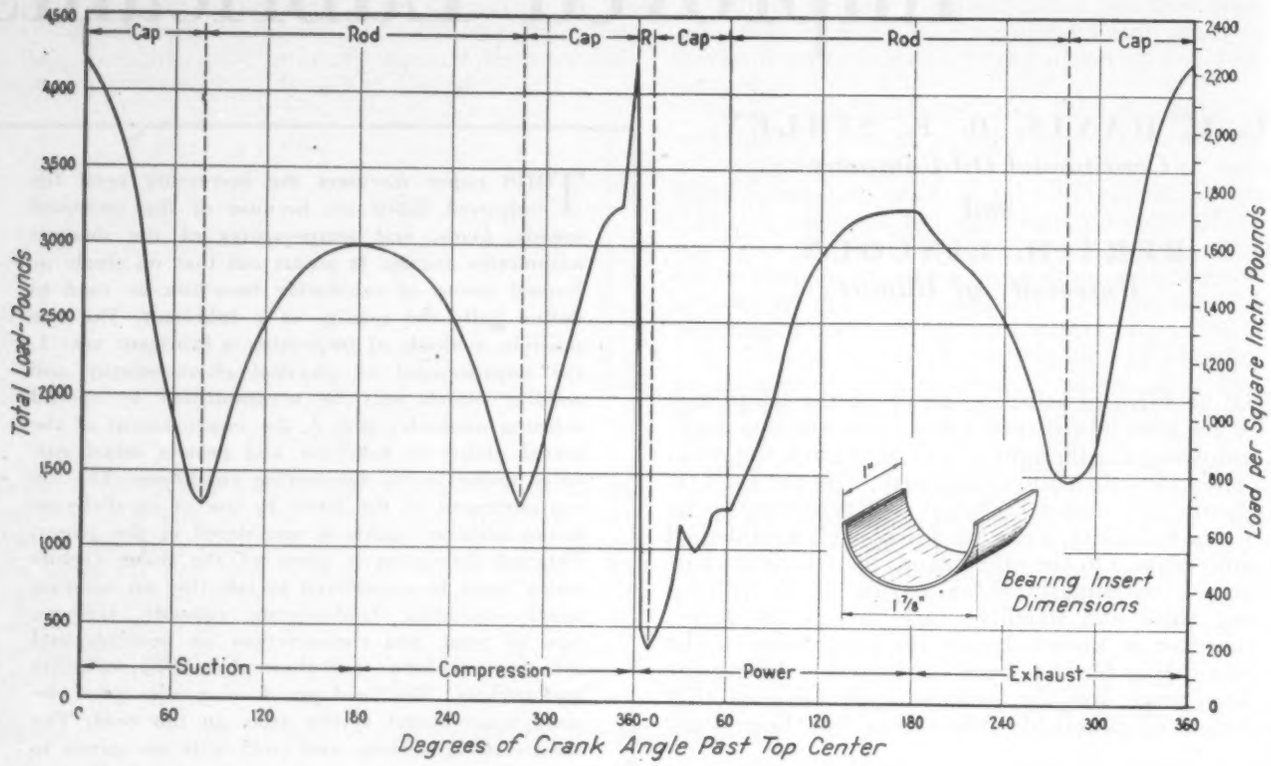

FIGURE 1
Connecting-Rod Loads for Full Load and Engine Speed of 4500 R.P.M.

The research staff was convinced, both from its own work and from the literature, that the desired lubricating improvement could best be obtained from the formation of an adsorbed film of the addition agent on metal surfaces. To form such a film of high adsorption energy a fatty-acid type of molecule was believed desirable, i.e., a long straight-chain hydrocarbon with very high polarity at one end. The work on the problem from the beginning, therefore, was to develop such a molecule. The first step was to increase the polarity of a fatty acid by halogenation. In the case of saturated acids such as palmitic or stearic, where the halogen enters the alpha carbon position,[5] very definite increases in polarity were obtained. The halogen, however, increased the acidity of the fatty acid to such an extent as to make the material unsatisfactory in automotive engines in the presence of soft metals. The next step was to overcome the acidic and still retain the polar characteristics. This was accomplished by methylating. Clark et al have described the theoretical study resulting in the selection of methyl-*a*, *a*-dichlorostearate,[6] and the present discussion will consider the laboratory and service proofs of the value of the product. The culmination of this development was the limited marketing in early 1933 and the extensive advertising and merchandising in early 1934 of a 0.75 percent blend of the chlorinated ester under the brand of Conoco Germ-Processed Motor Oil.

AUTOMOTIVE-ENGINE LUBRICATING REQUIREMENTS

In the meantime the increasing power, speed, and operating temperatures of modern automobile engines had greatly aggravated bearing troubles and had increased the difficulties of satisfactory lubrication. The increase in speed and power of automotive equipment during the past few years is too well known to call for further discussion in this paper, but it will be well to consider briefly the resulting conditions which must be met by the lubricant.

Sparrow,[7] in a discussion of bearing problems, has pointed out that the real peak loads on the connecting-rod bearings due to inertia and contrifugal force, plus the gas pressure, are actually many times as great as are commonly believed when considered from the viewpoint of gas pressure alone. Sparrow's "conventional guess" as to the total connecting-rod bearing loads, re-plotted by Sibley[8] to show two complete revolutions in a single graph, is given in Figure 1. The assumed conditions are a speed of 4500 revolutions per minute and full load. It will be seen that a maximum load of 2200 pounds per square inch of projected area is reached each revolution, and the unit load is over 1500 pounds for approximately one half of each revolution. The dotted vertical lines to the top of the chart indicate whether the load is on the "cap" or the "rod" side of the bearing. Sparrow states that the point of bearing failure usually occurs at the points of reversal of load between the cap and rod, rather than at the points of maximum pressure, and that this may be due to the lack of an established oil film at the moment of reversal.

The natural result of the increased speeds and loads has been a greatly increased operating temperature. To-

day crankcase temperatures of 250°F. are common, and in many of the 1935 models the crankcase temperature will go over 300°F. Although specific data are not at hand, it is evident that the actual film temperatures in the bearings are materially above these temperatures. The decrease in viscosity caused by these higher temperatures results in decreased oil pressure. The end leakage at the main bearings is increased, and the probability of the rod bearings receiving insufficient lubrication greatly increased. In addition to the actual oil starvation of the rod bearings, the viscosity may be so low at excessive temperatures that the oil may fail to carry the load. In addition to this, there has been a concerted effort on the part of automobile manufacturers toward the use of lower-viscosity oils such as SAE- 10 and 20 grades, thus again greatly decreasing the effective viscosity at operating temperatures.

These changes, viz., lower viscosity, increased loads, and high temperatures, have greatly decreased the safety factor for viscous lubrication. Dickinson and Bridgeman,[9] in their discussion of the fundamentals of automotive lubrication, have shown that the conditions of load and speed and viscosity now found in actual operation approach, if not actually pass, the critical point between viscous and boundary lubrication.

One of the results of the increased severity of operation has been the replacement of the conventional tin-babbitt bearings with special alloy bearings which are better able to withstand the increased speeds, loads, and temperatures. Three general types of "improved" bearing materials are now extensively used: 1, copper-lead matrix type, containing about 40 percent lead and 60 percent copper; 2, high-lead type, containing about 98 percent lead and two percent alkaline-earth metals; and, 3, the cadmium-silver and other cadmium alloys. Although these bearing metals are all superior to tin babbitt from the viewpoint of load-carrying capacity, they are unfortunately more sensitive to organic acids such as those resulting from the oxidation of the lubricating oil in service. This may result in a corrosion problem under high-temperature operating conditions.

THE USE OF ADDITION AGENTS

The increasing severity of automotive operating conditions, with the resultant need of improved lubricants and the successful development and marketing by major oil companies of oils with improved lubricating value, has resulted in a flood of "dopes" and "doped oils" which are claimed to be cure-alls for every engine trouble. Many of these dopes, frequently actually harmful to the engine, are sold by high-powered salesmen to gullible retail dealers who pass them along to motorists with all manner of ridiculous claims of merit. As a rule, these claims include that of high "film strength."

High film strength, if defined as the ability of a lubricant to carry high loads without bearing failure or excessive wear, is a desirable feature. Such a characteristic, however, may be misleading, or actually harmful, if the more essential lubrication characteristics such as rate of wear, corrosiveness, volatility, sludge formation, emulsibility, etc., are disregarded. The conditions under which some film-strength testers are operated by those selling "dopes" to be added to the oil in the crankcase are such that any chemically-active material will give high film strength. Thus any oil-soluble material containing loosely-combined halogens, sulfur or, for that matter, hydrochloric acid, free sulfur, and even powdered abrasives such as carborundum, give very high "film strength" by preventing metal seizure—although the rate of wear or corrosion may be excessive. It is, therefore, evident that a product should be looked upon with suspicion when the only evidence of quality offered is a film-strength demonstration without additional definite laboratory and performance data to prove that the product also meets all other lubricating requirements.

The difficulty is that we do not today have laboratory methods of measuring true lubricating value, which must include all of the factors which enter into the successful lubrication of a piece of equipment. A satisfactory lubricant must have the ability to carry the maximum possible loads at the maximum probable temperature without metal seizure or excessive wear; it should have low friction during the periods of thin-film operation; it must protect the metal parts against wear through metal-to-metal contact; it must form a protective film against corrosion from products of combustion or decomposition; it must be stable under the maximum possible operating conditions; it must be non-volatile, non-toxic, and odorless.

THE SELECTION OF AN ADDITION AGENT

The selection of a satisfactory addition agent to be used to improve the over-all lubricating value of a mineral oil is no easy task. Every phase of lubrication and metal protection must be given serious consideration. Our investigations have included the synthesis and study of over 1000 organic compounds, of which surprisingly few have proved of sufficient probable engine-lubrication value to justify detailed practical study. Four general steps are used in the selection of a compound: 1, theoretical investigation; 2, chemical laboratory study; 3, physical laboratory study; and 4, practical road tests.

1. The *theoretical investigation* includes the study of the physical and chemical forces of the adsorbed film on metal surfaces and the regimentation of molecules in oil solution, as discussed by Clark, Lincoln, and Sterrett.

2. *Chemical laboratory study*: After the synthesis and refining of a product, the chemical study—both of the pure agent and its solution in oil—considers such items as chemical and thermal stability, metal corrosion, toxicity, and effect on the oxidation stability and the physical characteristics of mineral oils produced from different types of crude and by various refining processes.

3. The *physical laboratory study* includes the measurement of film strength, load-carrying capacity, bearing-metal wear, oiliness and engine-dynamometer lubrication studies.

4. Four general classes of *supervised road tests* have been used:

   a. Controlled fleet tests.
   b. Supervised commercial fleet tests.
   c. Individual car tests under normal highway operation.
   d. Fleet tests under American Automobile Association supervision.

In all road tests the cars were completely overhauled and placed in comparable mechanical condition. Such detailed items as the use of torsion wrenches for making up cylinder-head bolts and the selection of matched sets of valve springs were given special consideration. In operation all comparison-test cars were run as a fleet under identical conditions, even to the degree of window openings for ventilation. The position of the cars in the fleet and the drivers were varied in a definite schedule. The cars were uniformly loaded with sand bags which

were adjusted to equalize the weight of the drivers. In other words, every known care was taken to minimize all variables except the quality of the oil under test. The total supervised road tests used in the development of methyldichlorostearate before it was placed on the market amounted to 963,000 car-miles, and the total test mileage on that product up to the present writing is nearly 2,000,000.

In the following discussion of our work the results obtained from the various laboratory and road tests will be arranged in accordance with their relationship to the various lubrication factors, such as bearing protection, cylinder-wall and piston-ring protection, sludge formation, etc. As the lubrication and protection of the bearing surfaces are the principal purposes of the lubricant, these will be given primary consideration.

Bearing failure or excessive wear occurs through the inability of the lubricant to prevent metal-to-metal contact under the given load, temperature, and speed. The load-carrying ability of a lubricant is studied in the laboratory by means of the Timken[10] and Almen[11] machines. As both machines are well known, a detailed description will not be included in this paper.

For purposes of comparison, the various addition agents tested are used in a one percent solution in a standard SAE-30 oil. For purposes of brevity the term "Chlor.-ester" will be used to designate methyl-*a*, *a*-dichlorostearate. In blends the regular commercial content of 0.75 percent of the chlor.-ester as used in Conoco Germ-Processed Motor Oil will be understood, unless other specific contents are mentioned.

TIMKEN FILM STRENGTH

The Timken "film strength" is defined as the load on the beam, in pounds, at 788 revolutions per minute and at 100°F. for 10 minutes, which gives incipient scarring of the bearing surfaces. In order to obtain reproducible results, particularly with mineral oils which may seize due to the slight jar when the load is placed on the beam, it was found necessary to use an automatic load-

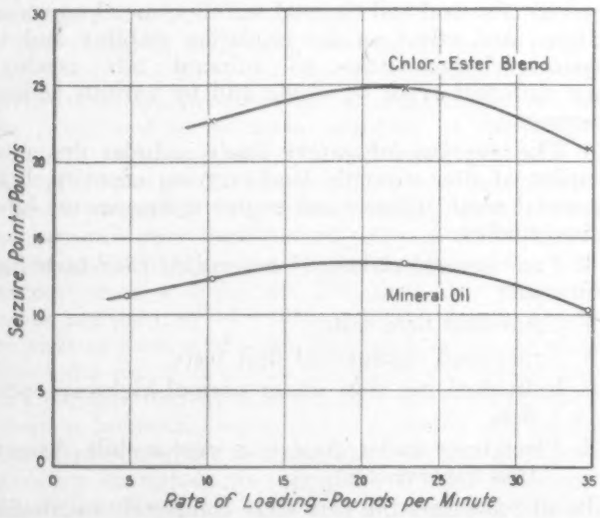

FIGURE 2

Relation between Timken film strength and rate of loading.

ing device. Figure 2 shows the effect of rate of loading on film strength. A standard rate of 22.8 pounds per minute is used in all Timken film-strength and wear tests.

The relationship between viscosity and film strength is shown in Figure 3. The lower curve is our regular Mid-Continent base mineral oil, and the upper curve is the same oil plus chlor.-ester. The vertical bars between the crosses represent the range in film strength of all the commercial mineral oils which we have tested. Practically every type of crude source and manufacturing

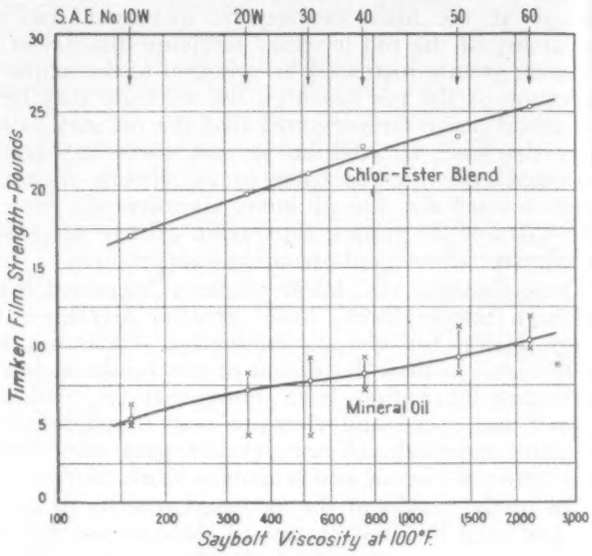

FIGURE 3

Relation between Timken film strength and viscosity.

process is represented. In general, we find that the greater the degree of refining, the lower the film strength of the oil from any given crude.

The Timken film strength does not consider rate of wear or corrosion and, therefore, is not an indication of what might be termed "useful load-carrying capacity." Long-time tests on the Timken machine indicate that the high rate of wear or "lapping in" takes place in the early stages of the test; and, that if a lubricant will carry a given load for 90 minutes, it will carry that load for an indefinite period without excessive wear. A useful load-carrying-capacity test was, therefore, developed—which consists of a series of 90-minute runs on the Timken machine using progressively-increasing loads until the oil fails to carry the load for 90 minutes. The number of minutes the last load was carried before failure is recorded. For rapid checking the following beam loads were used: 5, 7, 10, 15, 20, and each 10 pounds above 20. Table 1 shows the results of comparing a number of addition agents in one percent solutions in an SAE-30 oil by this method. This quite clearly shows that "high film strength" when considered alone

TABLE 1

The Relation Between Timken Film Strength and Load-Carrying Capacity

Addition Agent—1 Percent Added to Mineral Oil	Timken Film Strength (Pounds)	LOAD-CARRYING CAPACITY		
		No Seizure (Pounds)	Seizure (Pounds)	Seizure (Minutes)
SAE-30 mineral oil	8 8	10	15	1
Methyldichlorostearate	28	20	30	6
Trichlororesorcinol	125	20	30	46
Dichlorostearic acid	59	30	40	6
Dichloropropylether	44	15	20	30
Pentachloroethane	38	20	30	12
p-Chloroaniline	38	15	20	2
p-Chloroanisole	25.5	10	15	2
Chloropseudocumene	15.5	10	15	5
Hexyl chloride	8.8	10	15	2
Oleic acid	8.3	10	15	1

is not only meaningless, but may be decidedly misleading. Thus trichlororesorcinol, with a film strength of 125 pounds, shows but little better than methyldichlorostearate, which has a film strength only one-fourth as high. The reason for the mineral oil and the hexylchloride and oleic-acid blends carrying more long-time load than their film strength is probably due to the oxidation of the oil during the series of runs previous to the final maximum-load test.

TIMKEN WEAR TESTS ON BEARING METALS

The Timken film strength as determined with steel-on-steel surfaces cannot be used to predict the effect of a given lubricant on soft bearing metals. The soft metals are used in bearings because they have the ability to continue carrying loads without metal seizure after the oil film has ruptured. Under such conditions, however, the rate of wear is excessive.

The Timken machine may be used to study this factor by using a block of the bearing metal in question and a highly-polished steel cup. The standard cups used in the regular Timken test are unsatisfactory for use with soft metals, since they are sufficiently rough to abrade the soft metal at an excessive rate—and reproducible results cannot be obtained. This can be overcome by polishing or lapping the cup with Aloxite powder and oil.

A series of wear tests was made on various bearing metals of 30-minute duration, and the weight loss in grams of the bearing block was used as a measure of the rate of wear. A new polished cup was used for each metal and oil, but the same cup was used for the various beam loads i.e., 20, 40, 60, and 80 pounds. In all cases the cups were carefully inspected, and the better of each pair was used for the mineral oil. The approximate composition of the bearing metals used is given in Table 2, and the results of the wear test in Table 3. The oils used were the standard SAE-30 mineral oil and the same oil plus chlor.-ester. It is interesting to note that although the mineral oil will carry relatively high loads on the better bearing metals, the resultant rate of wear is materially higher than when the same oil carries a satisfactory addition agent.

TABLE 2
Approximate Composition of Bearing Metals

	BEARING-METAL ALLOY				
	SAE-11	Cadmium No. 50	Cadmium No. 51	Copper-Lead	Bronze F
Copper, percent	5.6	0.5	0.3	58.9	88.9
Lead, percent	0.3	....	....	40.0	....
Cadmium, percent	....	98.7	97.5	....	....
Silver, percent	....	0.8	2.2	....	....
Tin, percent	87.2	....	....	....	9.4
Zinc, percent	....	....	....	....	1.7
Antimony, percent	6.9	....	....	....	....
Nickel, percent	....	....	....	1.1	....

TABLE 3
Timken Wear Tests on Bearing Metals

METAL	OIL	LOAD ON BEAM— POUNDS			
		20	40	60	80
		Loss in Weight—Grams			
SAE-11	Mineral	0.0019	0.0040	0.0058	0.0091
	Chlor.-ester blend	0.0014	0.0026	0.0034	0.0071
Cadmium No. 50	Mineral	0.0026	0.0075	Seized	.....
	Chlor.-ester blend	0.0011	0.0056	0.0073	.....
Cadmium No. 51	Mineral	0.0025	0.0033	Seized	.....
	Chlor.-ester blend	0.0006	0.0030	0.0047	0.0062
Copper-Lead	Mineral	0.0013	0.0336	0.0390	Seized
	Chlor.-ester blend	0.0004	0.0035	0.0153	0.0316
Bronze No. F-1	Mineral	0.0129	Seized	.....	.....
	Chlor.-ester blend	0.0021	0.0015	0.0046	0.0054

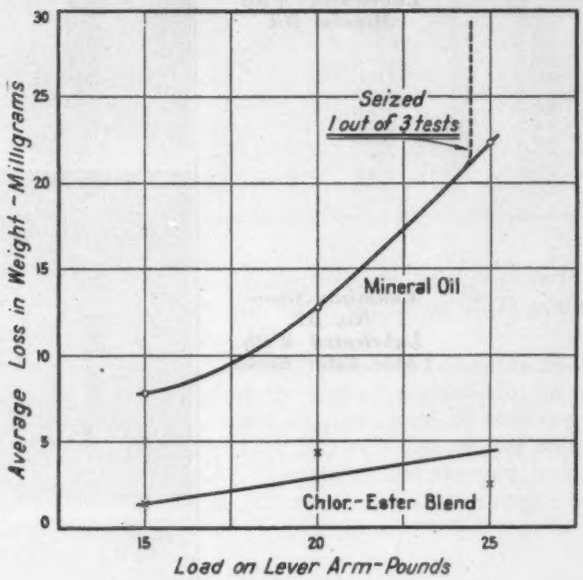

FIGURE 4
Timken long-time wear tests on cadmium-silver

In order to counteract any possible effect of differences in the cups, a series of six-hour runs was made with the same cup on cadmium-silver blocks at sufficiently low loads that the cup was not changed appreciably during the series. The average results of several runs are charted in Figure 4. In the case of the mineral oil at 25 pounds load, failure occurred in one run out of three.

This shows that at high load, but definitely below the seizure point or film strength of either oil, the chlor.-ester blend will result in less wear than the mineral oil. Similar studies have been made with other compounding agents; and, in general, it can be said that if the product has the highly polar film-forming characteristics which give oiliness and is not corrosive on the bearing metals or copper, the rate of wear will be low.

Photographs of the wear-test blocks for the cadmium-silver No. 51 and the bronze No. F-1 are given in Figure 5. Failure of the cadmium-silver with mineral oil at a load of 60 pounds is particularly interesting because it indicates a possible reason for the failure of these bearings in service. The mineral oil failed to maintain a lubricating film, and the resultant frictional heat was sufficient to melt the surface of the metal which was "wiped" out of the bearing. The chlor.-ester blend, even under 80 pounds load, maintained a sufficiently low friction to protect the bearing from failure. In the case of the bronze, the mineral oil under 20-pound load allowed twice the wear that resulted with the chlor.-ester blend under 80 pounds.

The Almen machine,[11] due to its portability, is being used in the field by several concerns for demonstrating the "film-strength" characteristics of oils and addition agents. Like the Timken machine, the Almen machine is

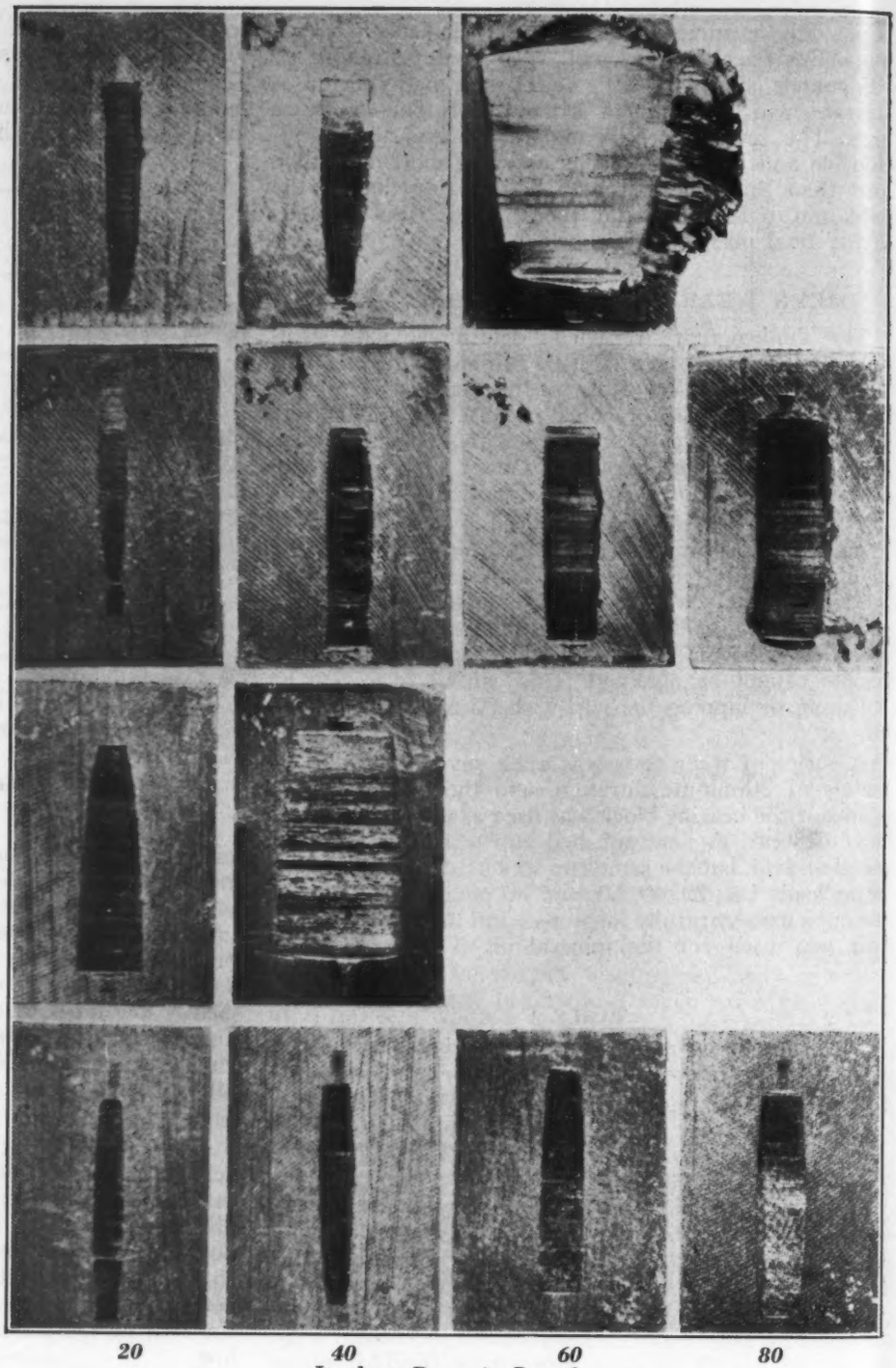
Cadmium-Silver No. 51 Lubricated With Mineral Oil
Cadmium-Silver No. 51 Lubricated With Chlor.-Ester Blend
Bearing Bronze No. F-1 Lubricated With Mineral Oil
Bearing Bronze No. F-1 Lubricated With Chlor.-Ester Blend
20
40
60
80
Load on Beam in Pounds

FIGURE 5
Bearing-metal blocks from Timken wear test.

normally operated with steel-on-steel bearing surfaces under such conditions as to show marked differences in film strength between a mineral oil and a lubricant containing an addition agent capable of preventing metal seizure. This test, therefore, may give high ratings on highly-corrosive materials. It is possible, however, to obtain useful information on the value of addition agents by using the Almen machine for long-time wear tests and with steel-on-bronze instead of steel-on-steel surfaces.

The results of the use of the Almen machine to study a group of addition agents are given in Table 4. The first column gives the standard Timken tests for purposes of comparison. The second column is the standard Almen film-strength test made with steel-on-steel at 600 revolutions per minute and applying the load at the rate of 1000 pounds per 10 seconds. The "film strength" is reported as the number of pounds per square inch of projected area the lubricant will carry for 10 seconds without seizure.

The third column is the Almen film strength using steel-on-bronze bearing metal instead of steel-on-steel. The test is conducted with the same procedure used in the regular Almen test. The fourth column gives the results of a one-hour wear test under a 2000-pound per square inch load. The loss in weight of the bronze pin, in grams, gives the relative wear.

The fifth column records the data from a three-

TABLE 4
Almen-Machine Film-Strength and Wear Tests

Oil Plus 1 Percent Addition Agent	Standard Timken Film Strength (Lbs.)	Almen Film Strength, Steel-on-Steel (Lbs.)	Almen Film Strength, Steel-on-Bronze (Lbs.)	ALMEN WEAR TESTS	
				Steel-on-Bronze (Loss in Grams)	Reversing Steel-on-Steel (Loss in Grams)
Mineral oil	9.3	3,500	6,000	0.586	0.451
Methyldichlorostearate	28	6,000	15,000+	0.036	0.003
Trichlororesorcinol	125	8,500	15,000+	0 006	0.003
Dichlorostearic acid	59	5,500	15,000+	0.003	0.003
Oleic acid	8.3	4,333	6,000	0.041	0.003
p-Chloroanisole	25.5	5,000	5,000	0.408	0.216
Dichloropropylether	44	6,500	6,000	0.477	0.008
Pentachloroethane	38	10,000	15,000+	0.002	0.006
Chlorodiphenyl	25.5	6,500	5,000	0.757	0.008
Chloropseudocumene	15.5	4,500	5,000	0.471	0.717
Tetrachloroethylene	15.5	7,000	5,000	0.611	0.004
Hexylchloride	8.8	5,500	15,000	0.266	0.208

hour reversing wear test of steel-on-steel. Long-time, straight-wear tests of steel-on-steel seem to have little significance, since if the test is operated at loads sufficiently below the film strength to permit completion of the test without seizure, the wear is inconsequential and appears to have little relation to the lubricant used. In actual service steel-on-steel bearings and journals are not used. The sliding of rings on cylinder walls is the only place where this combination occurs. In order to study the effect of a reciprocating action, a reversing mechanism was placed on the Almen machine —so designed that the machine operated in one direction at full speed, slowed to a full stop, and then accelerated to full speed in the opposite direction with a 1¼-minute cycle between stops. The reversing wear test was run for three hours, and the loss in weight of the pin, in grams, determined. The load was 2000 pounds per square inch.

A study of Table 4 reveals that film strength alone, without consideration of wear, does not fully define a satisfactory lubricant. In general, it would appear that both high Timken steel-on-steel and high Almen steel-on-bronze film strengths are required for low wear. The only exception to this is oleic acid, which shows low wear in both tests but has poor film strength by all methods.

The excessive wear obtained with mineral oil in both wear tests indicated the desirability of studying wear at lower loads. Table 5 gives the results of a series of wear tests at different loads for a mineral oil and the same oil plus chlor.-ester. Up to a load of 1000 pounds per square inch, the wear appears to be of the same order and within the probable reproducibility of the test. At 2000 pounds, however, the mineral oil again shows excessive wear. The very low wear at excessive loads resulting from the use of the chlor.-ester blend seems to be an unusual property, as with the exception of chlorinated stearic acid all other products we have examined which show low year at 2000-pound loads will either seize or show greatly increased wear at an 8000-pound load. Thus pentachloroethane, which shows the lowest average wear we have found at 2000 pounds, seizes at 8000 pounds.

TABLE 5
Almen-Machine One-Hour Wear Tests—Steel-on-Brass

LOAD—(Pounds per Square Inch)	Grams Loss in Weight of Brass Pin	
	Mineral Oil	Chlor.-Ester Blend
250	0.012	0.008
500	0.010	0.014
1,000	0.058	0.050
2,000	0.859	0.040
4,000	Seized	0.036
6,000	.....	0.017
8,000	.....	0.009

The Almen "film strength" is very sensitive to the speed used, and materially higher results can be obtained at lower than the designed speed of 600 revolutions per minute. Thus at 200 revolutions per minute chlor.-ester blend SAE-30 carries an average load of 13,000 pounds, and at 160 revolutions per minute over 17,000 pounds.

BEARING-METAL CORROSION

It is self evident that a lubricant as well as its components must be non-corrosive on any metals with which it will come in contact during distribution and use. The more easily corroded metals found in automotive engines are copper and various bearing metals, particularly those containing lead and cadmium. The study of the action of compounding agents on these metals must consider three factors:

1. They must be stable and non-corrosive in their unblended concentrated state.

2. They must not decompose in service to form corrosive materials.

3. They must not accelerate the oxidation of the mineral oil to form corrosive products, but should act preferably as inhibitors.

The first factor is easily tested by any of the usual strip-corrosion tests on the compounding agent itself. The second and third factors must be considered together, since the blended oil is used in service, and the resultant chemical activity is due to both factors. In view of the present chaotic condition surrounding laboratory bearing-metal corrosion tests, we hesitate to discuss the subject; however, we have found the simple "beaker" test to be of real value in forecasting the corrosion characteristics of lubricants in service. Such a test will not show small differences between oils; but, along with the other characteristics, will certainly help in discarding the large majority of questionable products.

The "beaker" corrosion test is conducted as follows: 200 ml. of the oil is placed in a 250-ml. Erlenmeyer flask which is set into an oil bath at 300°F. The test metal strips, one inch by three inches in size are suspended separately in a circular arrangement around the center of the flask, and are immersed for 80 percent of their height. Moist air, in the amount of two liters per hour, is bubbled through the oil during the test which lasts 43 hours. At the end of the test the strips are cleaned with naphtha and acetone, and the loss in weight determined. The test is run in duplicate; and, if

the discrepancy between duplicate tests is too great, additional runs are made to obtain a reasonable average. The very nature of the test makes accurate checks difficult, but the relative degree of corrosiveness of several products may be obtained with reasonable accuracy.

All types of metals found in automotive equipment, particularly bearing metals, have been studied; but we have found that a preliminary test using copper and copper-lead bearing metal will rate lubricants satisfactorily. Products which pass this test may then be tested on other metals such as cadmium-alloy or lead-alkaline-earth-metal bearings. The results of the standard corrosion test on a number of lubricants are given in Table 6.

The group of mineral oils is interesting in that the wide range of corrosion found on supposedly satisfactory mineral oils is surprising. The first (No. 1) is our Mid-Continent base mineral oil. The other five are extensively-advertised and widely-distributed brands. That this factor of corrosion by mineral oils cannot be overlooked is proved by the fact that in actual road tests with such oils copper-lead bearing failures have occurred through corrosion in 3000 to 8000 miles of operation.

The second group shows the corrosion resulting from various addition agents compounded with mineral-oil base No. 1. The Timken film strength is given for reference. It will be seen at once that a high film strength may mean a highly-corrosive product. The very low corrosion reported for pentachloroethane is due to the extreme volatility of the addition agent, which allows the practically-complete evaporation of the agent during the first part of the run. At the end of the test only 0.08 percent remained in the oil.

The third group shows the corrosion test on a number of branded, commercial, compounded oils purchased on the open market. Instead of giving brand names, we are giving the best information we have on the chemical nature of the addition agent used. It will be seen that the majority of these products are highly corrosive. On the other hand, the chlor.-ester blend shows only a slightly greater loss than the mineral-oil base and much less than the average mineral oil.

The chief objection to the beaker corrosion test is that some products, particularly those which sludge badly, form a protective coat over the test strip, and the result indicates little or no corrosion. As an example, trichlororesorcinol (No. 11) shows a high corrosion on copper; but, due to the formation of a protective sludge film on the copper-lead, indicates no corrosion on that metal. In general, if a product shows little or no corrosion on both copper and copper-lead and if the oil is clear after the test, indicating no sludge formation, it is reasonably safe to assume that the product is non-corrosive, and road tests as final proof are justified.

TABLE 6
Beaker Corrosion Test on Bearing Metals

PRODUCT SAE-30	Agent Used (Percent)	LOSS—MILLIGRAMS PER 100 SQ. CM.			Timken Film Strength (Pounds)
		Copper	Copper-Lead	Cadmium-Silver	
Plain Mineral Oils:					
1. Conoco Mid-Continent base	...	2	2	0.6	8.8
2. Solvent-treated Mid-Continent base	...	7.5	10	...	7.3
3. Solvent-treated Eastern base	...	10	12	...	5.3
4. Eastern base	...	7.5	23	...	8.3
5. Naphthene base	...	16	36	...	9.6
6. Eastern base	...	6.8	1.2	...	8.3
Oil No. 1 Plus Addition Agent:					
7. Methyldichlorostearate	1	4.5	5.2	...	28
8. Pentachloroethane	1	2	2	...	...
9. Dichloropropylether	1	8	10	1.4	44
10. Trichlorophenol	1	...	15	...	49
11. Trichlororesorcinol	1	25	1	...	125
12. Triphenylchloromethane	1	77	95	0	74
13. p-Chloroanisole	1	69	79	0.5	26
14. Dichlorostearic acid	1	...	140	16	45
15. Oleic acid	1	...	430	485	8.3
Commercial Compounded Oils:					
16. Chlor.-ester blend	0.75	2.7	4.8	1.6	23
17. Isopropyl esters of oxidized wax	2	16	116	...	4.3
18. Chlorinated petroleum hydrocarbons, probably wax	...	42	65	...	21
19. Processed castor oil	5	13	150	123	10.8
20. Chlorinated petroleum	0.2*	16	90	...	36
21. Ketones, etc., from oxidized petroleum	...	19	40	...	15
22. Chlorinated hydrogenated fish oil	0.3*	49	153	...	19
23. Chlorinated diphenyl	0.4*	3	31	...	25
24. Pentachloroethane	2.0*	27	5	...	28
25. Chlorinated naphthalene	1.2*	2	66	...	31
26. Esterified oxidized petroleum hydrocarbons	3	5	35	...	17
27. Voltolized glyceride	10	8	22	...	...

* Percent of chlorine in blend.

The beaker corrosion test is of questionable value on cadmium alloys, as protective sludge films form readily on those metals. As an example, both parachloroanisole and dichlorostearic acid show little corrosion on cadmium-silver, although both products are highly corrosive on copper-lead.

A connecting-rod-bearing corrosion-testing machine, recently designed by B. E. Sibley, overcomes this difficulty by continually removing the protective film. The Sibley machine (Figure 6) consists of standard connecting rods placed on a shaft which rotates at 1800 revolutions per minute. A 15-pound load is placed on the rods by means of a spring. Oil is circulated under 30-pound pressure from a heated sump through the drilled shaft to the bearings. A test is run for 22 hours at 350°F. The amount of corrosion on the bearing inserts is determined as the loss of weight in grams. Table 7 shows the results of runs made on cadmium-silver and copper-lead bearings with four different oils. The chlor.-ester blend is our regular commercial SAE-30 grade, and the mineral oil is the same product without the addition agent. The two solvent-treated oils are products made from a Mid-Continent and an Eastern crude source, respectively. Two runs are given for the solvent-treated Mid-Continent base oil. At the time of writing, data were not available for our mineral

oil on copper-lead. The difference in metal-weight loss between the chlor.-ester blend and the mineral oils is entirely too great to be explained by a difference in corrosiveness, but indicates an actual protection of the metal from corrosion. This protection must be due to the adsorbed film built up on the metal surface by the addition agent.

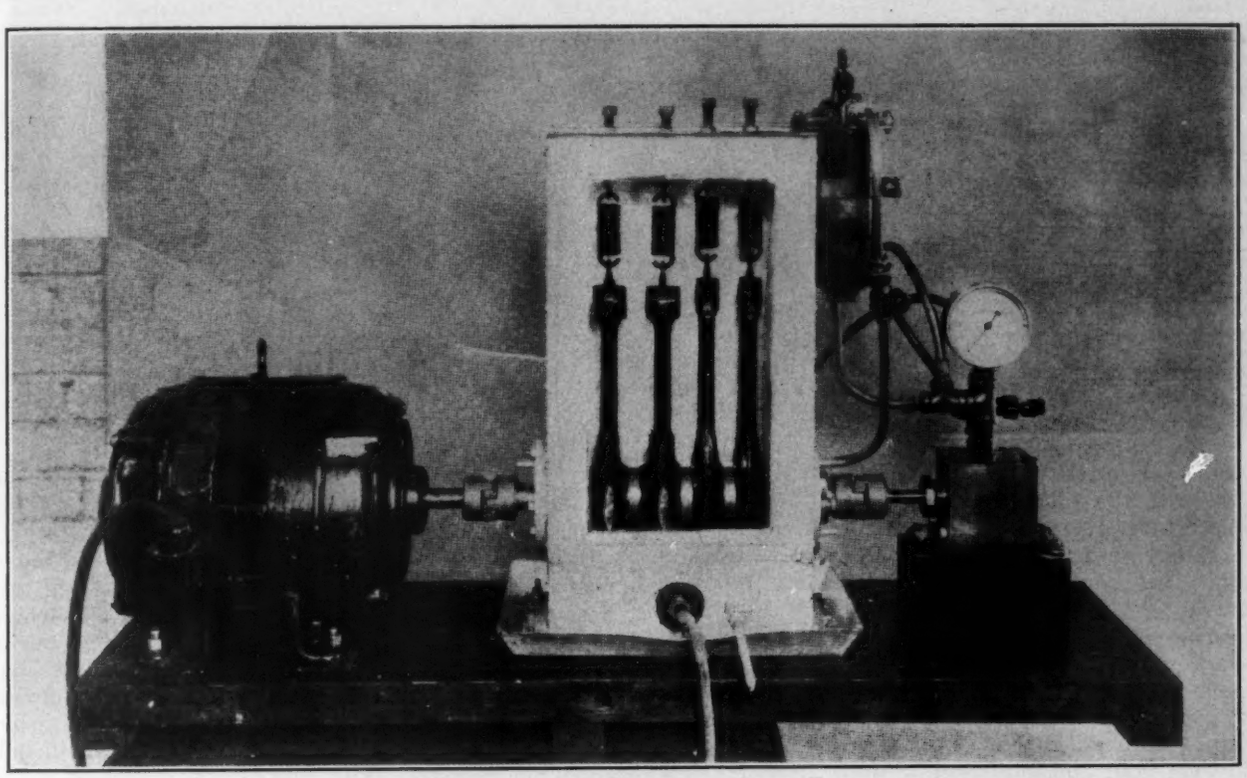

FIGURE 6
Sibley connecting-rod-bearing corrosion machine

BEARING PROTECTION IN SERVICE

The primary purpose of a lubricant is the protection of bearing surfaces from wear. "Wear" in automotive bearings results from direct chemical corrosion and mechanical abrasion. It is impossible to isolate the effects of these two factors, but it is certain that both enter into bearing wear under actual service conditions.

We have shown that the oxidation products of some mineral oils, particularly of the highly-paraffinic type, are highly corrosive on the newer type of bearing metals. Actual road tests under high temperatures of operation confirm this.

The question of mechanical wear is not quite as clear. Certainly if ample oil were available at all times to furnish viscous lubrication, there would be no mechanical wear. This is proved by the fact that properly-designed and lubricated industrial equipment shows practically no bearing wear. On the other hand, automotive bearings do show wear; and, as discussed above, today's automotive bearings under present loads and temperatures do reach boundary or thin-film lubricating conditions. Under such conditions the improved lubricating value obtained by a good addition agent should manifest itself in less bearing wear. Road tests to prove this must of necessity be over long periods of time, and to prove the value of the addition agent must

TABLE 7
Connecting-Rod-Bearing Corrosion Tests on Sibley Machine

	WEIGHT LOSS IN GRAMS				
	Continental Oils		Solvent-Treated Oils		
	Chlor.-Ester Blend	Mineral	Mid-Continent Base	Mid-Continent Base	Eastern Base
Cadmium-Silver Bearings:					
No. 1 cap insert	0.0864	0.9526	1.2506	1.5801	2.1586
No. 1 rod insert	0.0980	0.9105	0.9724	1.4921	0.4365
No. 2 cap insert	0.0789	0.9818	1.7419	1.9430	1.4616
No. 2 rod insert	0.0709	0.8782	0.8981	1.3298	2.0556
Average loss per insert	0.0836	0.9308	1.2158	1.5863	1.5381
Copper-Lead Bearings:					
No. 5 cap insert	0.0079	.....	0.2118	0.3007	0.4387
No. 5 rod insert	0.0191	.....	0.2673	0.2259	0.3929
No. 8 cap insert	0.0111	.....	0.1964	0.3170	0.4484
No. 8 rod insert	0.0176	.....	0.2153	0.2944	0.3962
Average loss per insert	0.0139	.....	0.2227	0 2845	0.4191
Length of test, hours	22	22	22	22½	22
Average oil pressure, lbs. per sq. in.	29	35	29	33	33

TABLE 8
Rate of Wear of Connecting-Rod Bearings in Service

Percentage Composition of Bearing Metal	CAR	SPEED	Rate of Wear of Connecting-Rod Bearings (Grams per 10,000 Miles)	
			Mineral Oil	Chlor.-Ester Blend
Copper-Lead: Copper—58.9 Lead—40 Nickel—1.1	Studebaker*	Break-in	0.0924	0.0728
	Studebaker*	4,000 r.p.m.	0.5183	0.4569
	Studebaker†	50+ m.p.h.	0.3424	0.1174
	Studebaker†	50+ m.p.h.	0.4232	0.2315
	Buick-8‡	50 m.p.h.	0.0544	0.0449
High Lead: Lead—98 Alkaline-earth metals—2	Buick-8‡	Break-in	0.1864	0.1856
	Buick-8‡	50 m.p.h.	0.1024	0.0955
Copper-Lead: Lead—36 Copper—64	Ford V-8 truck§	Break-in	0.8232	0.7112
	Ford V-8 truck§	50 m.p.h.	0.3781	0.2583
Cadmium-Silver:	Pontiac, 1935¶	50+ m.p.h.	.....	0.0922

* Studebaker model "C" President engine connected to a G. E. 150-h.p. dynamometer.
† Studebaker model "C" 1934 President coupe.
‡ Conoco test fleet of Buick-8, model 33-67, 4-door sedans equipped with special bearings as noted.
§ Conoco Ford truck test fleet, Ford V-8 1½ ton trucks.
¶ Pontiac-8—1935 sedan.

be made in comparison between a mineral oil and the same oil with the added compound.

Such comparative road tests between our mineral-oil base and the same oil plus chlor.-ester are shown in Table 8. The connecting rod bearing wear is reported as the average loss of weight in grams of all connecting rod bearings in the car. For ease of comparison, all losses are reported as grams loss per 10,000 miles of operation. Where a "break-in" run is reported, the freshly overhauled engine, with new bearings, was given our standard break-in run of 2500 miles—starting at 25 miles per hour and increasing in uniform increments to 50 miles per hour at the end of the period. It is interesting to note that, with the exception of the dynamometer engine tests, the rate of wear during the break-in period is materially greater than during the running period. In all cases the chlor.-ester blend shows better bearing protection than the mineral oil. Since the corrosion characteristics of the two oils by laboratory test are very low and of the same degree, we believe that the greater bearing metal protection of the chlor.-ester blend is due to its greater lubricating value as indicated by the wear tests discussed above.

Comparative figures are not given for cadmium-silver bearings, as our study of that material is not complete at this writing. We are simply showing an actual rate of wear determination made under summer-driving conditions at speeds of 50-70 miles per hour. This shows that this bearing is fully protected by the chlor.-ester blend under the severe conditions.

CYLINDER AND PISTON-RING PROTECTION

Until recently it has been generally assumed that cylinder wear results from direct abrasion between the piston rings and the cylinder walls. More recent information indicates that it is largely the result of corrosion from the products of combustion, and that the greater part of this wear takes place during the starting period before the cylinder walls have reached a sufficiently high temperature to prevent water condensation on the surface.

Teetor[12] has shown that true abrasion may result when the cylinder walls are distorted from a true cylinder by non-uniform cooling from the water jacket or by the cylinder head stud bolts. This abrasion is local in character, and probably ceases after the cylinder has more nearly reached a true circle at operating temperatures. Abrasion may also occur because of piston slap, but Heldt[13] presents data indicating that the greatest wear is not, as a rule, across the cylinder.

In 1932 Boerlage and Gravesteyn,[14] in reporting on their work on Diesel engine cylinder wear, stated that: "Immediately after starting up, the wear of an engine is a multiple of that during normal running; normal conditions are usually reached after two to three hours running." Their procedure was to determine the amount of mineral matter removed from the engine by ashing all of the lubricant drained from the cylinder in half-hourly increments. Operating on their standard low-wear fuel, they showed the total ash during the first hour to be approximately 237 mg.; the second hour, 117; the third hour, 35; and thereafter, 30 mg. per hour. In other words, the rate of wear during the first hour was eight times as great as during normal operation.

One of the most complete studies of the factors causing cylinder wear has been made by the Institution of Automobile Engineers, and reported by W. N. Duff.[15] This study included all the factors commonly supposed to affect wear; and indicated that such factors as speed, load, low oil supply, high temperatures, dilution, and even abrasive content (except at dilutions over 80 percent) have little of no effect on cylinder and piston ring wear. The only condition which seemed to affect the rate of wear greatly was operation at cylinder wall temperatures below 194°F. Under these conditions wear is also accelerated by lack of oil supply, the greatest wear taking place at low temperatures and with low oil supply. Continuous engine runs with a cylinder wall temperature of 122°F. showed eight times the wear that took place at 212°F. Successive starting tests, in which the starting temperature was 77°F. and in which warming up was delayed by idling for five minutes, although oil was supplied from the start, showed about three times the rate of wear found in normal operation. Similar tests, in which the oil supply was delayed for 10 minutes, showed 14 times greater wear than under normal operation.

These investigators present the hypothesis that cylinder "wear" is largely the result of corrosion by the products of combustion during operation—particularly while starting—when the cylinder wall temperatures are below 194°F. Tests with hydrogen as a fuel compared to gasoline showed a cylinder-wall reduction in wear in the ratio of 2.6 to 1 and a top-piston-ring wear

TABLE 9
Cylinder and Piston-Ring Wear

	Amount of Wear with Chlor.-Ester Blend	Amount of Wear with Mineral Oil	Percent Greater Wear with Mineral Oil
Buick Test Fleet—15,000 Miles:			
Oil-ring wear, g	0.1311	0.1795	37
Compression-ring wear, g	0.1666	0.3692	121
Total ring wear, g	0.2977	0.5487	84
Average cylinder wear, in.	0.00021	0.00029	38
Ford Truck Test Fleet—12,500 Miles:			
Oil-ring wear, g	0.0753	0.1119	48
Compression-ring wear, g	0.0791	0.1275	61
Total ring wear, g	0.1544	0.2394	55
Average cylinder wear, in.	0.00018	0.00029	62
Chevrolet Test Fleet—30,000 Miles:			
Oil-ring wear, g	0.2621	0.4664	78
Compression-ring wear, g	0.3522	0.3828	9
Total ring wear, g	0.6143	0.8492	38
Average cylinder wear, in.	0.00019	0.00023	21

of 5.7 to 1. As wear was not completely stopped, the remaining wear may be due either to nitrogen acids formed or to abrasion.

They point out that if this is true, a lubricant which gives better protection should decrease wear; and they show, in actual engine tests, that a proprietary oil containing 0.6 percent of a vegetable acid base showed a reduction of piston ring wear of 40 percent, and of cylinder wear of 25 percent. They also showed that a simple strip-corrosion test in a steam atmosphere would show the difference between mineral and compounded oils.

In developing this corrosion test in our laboratory, we used a 12-inch diameter wheel rotating horizontally at 15 revolutions per minute. Test strips were arranged radially around the perimeter. As the wheel rotated, the test strips came in contact with a jet of saturated steam to which could be added vapors of hydrochloric, acetic, and formic acids, carbon dioxide, etc. After one hour, rust was carefully removed, and the loss in weight determined. With straight steam, an SAE-30 mineral oil showed 60 percent greater loss than the same oil containing one percent chlor.-ester; and, in the presence of carbon dioxide and traces of hydrochloric and acetic acids, the mineral oil showed approximately 35 percent greater wear.

Everett and Stewart[16] and Keller[17] have determined wear by the increase in iron content of the crankcase oil. Briefly, they have shown that, under the conditions of their operation, the iron removed from the engine during the first hour of operation is approximately four times as great as the average rate of removal per hour during the succeeding five hours.

In measuring the rate of wear in our laboratory, we have used the same Chevrolet engine-dynamometer assembly used for consumption tests.[18] After several flushing charges—until the flushing oil showed no iron increase—the engine stood at room temperature (85-90° F.) for one hour. The water jacket was cooled to 35°F. A six-quart charge of oil was added to the outside sump at room temperature, and the engine started under load. The cooling water temperature was allowed to rise uniformly until the normal running temperature of 180°F. was reached in one hour. Typical results show the iron removal for the first hour was 0.0204 g. for the mineral oil and 0.0104 g. for the same oil plus chlor.-ester. The average rate of iron removal for the five succeeding hours was 0.0020 g. and 0.0010 g. per hour, respectively.

This shows the rate of wear for the mineral oil is twice as great as for the chlor.-ester blend, and that the starting wear, i.e., for the first hour, is 10 times as great as for the normal running period.

Thus a decided advantage is indicated in the use of a carefully-selected, strongly-polar addition agent in a lubricant entirely separate and in addition to any lubrication value resulting from its film strength and oiliness.

CYLINDER PROTECTION IN SERVICE

Cylinder and piston-ring wear was determined in connection with car and fleet-test work in connection with the development of the new addition agents. The results of three such runs are given in Table 9. The actual ring wear as determined by loss in weight is substantial, and in all cases shows a materially greater wear for the mineral oil than for the chlor.-ester blend.

In all cases the cylinder wear is surprisingly low. All test runs were made at 50 miles per hour under high-temperature conditions. There were relatively few starts and stops for mileage covered and, therefore, the low wear measured is added proof that corrosion under starting conditions is the cause of the major portion of cylinder wear.

The cylinder-wear figures are the average of six measurements for each cylinder. Measurements were taken at the top, middle, and bottom of each cylinder—and both lengthwise and across the block at each point. Precision gages, checked by accurate ring gages, readable to two points in the fifth place, were used. Measurements before and after runs were made at identically the same points, and sufficient readings were taken accurately to "bracket" the true reading. All measurements were corrected for temperature.

The differences in cylinder wear, although small, show substantially in favor of the chlor.-ester blend; the average wear with the mineral oil is 40 percent greater than with the compounded oil. Using the wear figures for the top of cylinders, the difference becomes greater: thus, in the case of the Buick fleet the average top-cylinder wear with the chlor.-ester blend was 0.00027 inch, and for the mineral oil 0.00040 inch—an increase of 48 percent over that for the compounded oil.

STABILITY OF COMPOUNDED OIL

One of the most important factors in the selection of an addition agent is the question of its effect on the stability of the oil in which it is blended. Many products which are very desirable from the viewpoint of film strength, oiliness, low wear, etc., prove to be oxidation catalysts, and increase the rate of sludge and acid formation in the crankcase oil.

A desirable product should show either no catalytic action or a negative one. The amount of sludge formed during the "breaker" corrosion test discussed above is a good preliminary test for this factor. Table 10 gives the amount of sludge, in milligrams, produced per 10 g. of oil during the corrosion test. This indicates that high-film-strength products may be powerful sludge-forming catalysts.

There is no satisfactory laboratory method available

TABLE 10
Sludge Formation in Corrosion Test

	Milligrams per 10 Grams of Oil	Timken Film Strength (Pounds)
All mineral oils	None to 1.4	...
Methyldichlorostearate	None	28
Trichlororesorcinol	64	125
Triphenylchloromethane	27	74
Dichlorotetralin	43	95

today which will measure the relative stability of lubricants in terms of the actual changes they will undergo in service. The present available oxidation tests are of little practical value for this purpose, since they disregard the catalytic effect of the metals with which they will be in contact during service and the contamination from fuel, air dust, cooling agents, etc. It is, therefore, necessary to depend upon actual tests on the road to study crankcase-oil service changes.

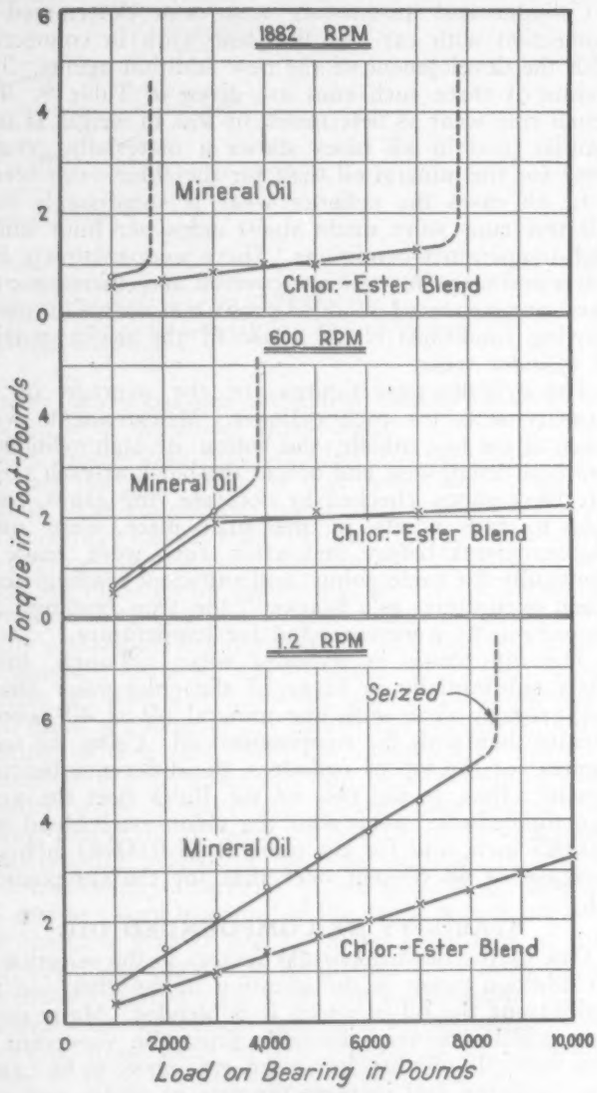

FIGURE 7

Relation between Almen-machine torque, load, and speed with steel on bronze.

The results of the comparison of four oils in the Conoco Chevrolet test fleet are given in Table 11. The test represents a total of 30,000 miles on each of five test cars. Runs of 1100 miles were made between crankcase changes at an average speed of 50 miles per hour over Oklahoma highways under July and August operating conditions.

Two mineral oils and the same oils blended with 0.75 percent chlor-ester were used. Oil No. 1 was a highly-refined acid-treated Mid-Continent-base oil; oil No. 2 was a solvent-treated Mid-Continent oil. Both oils were SAE-20 grade. The characteristics of the fresh oil are given in the table.

The stability of the oils, as indicated by the Sligh and the Indiana oxidation-stability tests, indicate considerable superiority on the part of the solvent-treated oil. The Indiana tests indicate that the addition agent improves the stability of the acid-treated oil, and has little or no effect on the solvent-treated oil.

The actual service changes found in the road tests are given in terms of the average sludge and acid formed per 1100-mile run between crankcase-oil changes. The results show: 1, that the wide differences found by the laboratory oxidation tests between solvent-treated and acid-treated oils do not occur in service; and, 2, that the addition of the chlor.-ester tends to decrease rather than to increase the amount of oxidation of an oil in service.

It is essential that a crankcase lubricant does not produce corrosive decomposition products in service; and, therefore, the corrosiveness of the used crankcase oil is of value. The last section of Table 11 gives the average corrosion on copper and copper-lead bearing metal for the four oils in question after 1100 miles of service. Compared with Table 6, it will be seen that there has been little change in this factor during use.

OILINESS

The greatly over-worked word "oiliness" has been used to cover a multitude of opinions and hypotheses on the theory of lubrication. We believe that, from its historical development, it should be limited to that phase of lubrication which considers the coefficient of friction under boundary and thin-film conditions. A low friction under all conditions of lubrication is desirable, but under boundary lubrication it is essential. This importance is not due to loss of power, but to the increased production of heat through high friction. The frictional loss of power in the modern engine is but a small fraction of the total available power and is, therefore, of minor importance. The heat resulting from boundary lubrication with an oil of low oiliness may quickly result in temperatures so high that a mineral-oil film fails. A compounded oil may have oiliness without high load-carrying ability. This is characteristic of the fatty acids, which under thin-film conditions—but below their film strength—will show low friction and prevent failure by keeping the temperature at a safe point. The newer products, such as chlorinated esters, may have both oiliness and film strength—which permits the oiliness characteristics to function at higher

TABLE 11

Crankcase-Oil Stability in Service

	Mineral Oil No. 1	No. 1 Plus Chlor.-Ester	Mineral Oil No. 2	No. 2 Plus Chlor.-Ester
Fresh Oil:				
Gravity	26.9	26.4	28.7	28.8
Flash point	430	430	430	430
Fire point	495	490	490	490
Viscosity at 100° F.	354	345	345	335
Viscosity at 210° F.	53.8	53.3	54.9	54.6
True color	29	29	24	24
Neutralization No.	0.028	0.045	0.045	0.045
Carbon residue, percent	0.25	0.25	0.13	0.12
Sligh No.	13	16	1.6	0.2
Indiana Oxidation Test:				
Hours to produce:				
100 mg. sludge per 10 g. of oil	38	45	99	96
1.0 neutralization No.	30	38	47	46
True-color increase, 50 hours	34	31	18	20
Chevrolet Fleet Runs:				
Average percent sludge per 1,100-mile run	0.41	0.35	0.33	0.32
Average neutralization No. for 1,100-mile run	0.358	0.315	0.248	0.245
Average true color	277	276	157	155
Corrosiveness of Used Crankcase Oil:				
Milligrams loss per 100 sq. cm.:				
Copper	4.8	2.7	11.7	13.9
Copper-lead	3.0	4.8	24.0	20.6

loads and temperatures than in the case of the fatty acids.

It is probable that the characteristics of oiliness, as differentiated from film strength, is the result of the formation of a true adsorbed film of substantial thickness and permanence by polar molecules. Clark, Lincoln, and Sterrett, as well as many others, have shown that such films are unquestionably formed. It is, therefore, probable that the adsorbed film which gives oiliness is that which also gives metal protection against corrosion.

The relative oiliness value of two oils may be shown on any laboratory apparatus which will measure the resistance to motion of surfaces under thin-film conditions. The relative values, however, may change widely—depending upon the conditions of test, metals used, etc. The scope of this paper does not justify an extensive discussion of the many methods of measuring oiliness to be found in the literature, but we will give a single example for illustrative purposes.

Figure 7 shows the relationship between torque and load on an Almen machine, using a steel bushing and bronze pin at 1.2, 600, and 1882 revolutions per minute. The results are shown for SAE-30 mineral oil and for the same oil plus chlor.-ester. It is particularly interesting to note the decrease in load-carrying ability of the mineral oil with increased speed.

It is impossible in practical road tests to isolate the effects of oiliness as defined above. However, in all our road work we have found a definite lower operating temperature as measured by the differential increase in water temperature, temperature of oil from the bearings, and the oil-sump temperature, for the blended oil as compared to the mineral oil under comparable operating conditions. As an example, in the Chevrolet fleet tests, where the comparisons were carried out under conditions as nearly identical as was physically possible, the average sump temperature of the cars on the chlor-ester blend ran 8-10°F. below those on mineral oil.

Probably the best example we have of this characteristic was made at the Indianapolis speedway, where a Studebaker racing car was under test at 104 miles per hour. Switching from mineral oil to chlor.-ester blend and back showed an average lower sump temperature of 20°F. under identical driving conditions.

MISCELLANEOUS CHARACTERISTICS

Consumption of Oil in Service

The question of a relationship between oil consumption and the use of an addition agent is controversial, and must depend upon the future for final proof. The best available information we have, both from dynamometer and road tests, indicates a decrease in consumption with the addition of chlor.-ester and similar oiliness agents. The many factors entering into the consumption of crankcase oil make it difficult to isolate any one factor; however, in fleet tests, in which the consumption of oil in each car was calibrated before and after the test with the same oil and the individual car's consumption corrected by that calibration, the chlor.-ester blend shows an average lower consumption than the mineral oil. Thus, in the Ford test fleet the blend showed an average mileage of 359.9 miles per quart as compared to the mineral-oil average of 309.0, or an increase in mileage of 16 percent.

Under abnormally severe operating conditions, much greater differences are found. Thus, in the case of the Buick fleet during tests on Pikes Peak, the mineral oil showed a mileage per quart of only 237.5 as compared to the 403 for oil containing chlor.-ester. In this case, all the cars in the fleet when new had been adjusted to show the same consumption. After 25,000 miles of severe operation, including the abnormal alternation of extreme heat and cold in the Peak tests, the car lubricated with mineral oil showed excessive cylinder and ring wear which resulted in excessive consumption. The large difference in consumption found in these tests is, therefore, the result of the differential wear rather than inherent differences in the factors controlling the rate of consumption.

Consumption of Addition Agent in Service

An addition agent may be consumed in service at a greater rate than the oil, due to either decomposition or vaporization. Such very volatile agents as pentachloroethane, dichloroethylether, dichloropropylether, tetrachloroethylene, etc., vaporize rapidly under high-temperature operating conditions — thus making them unsatisfactory for practical use, regardless of film strength.

Many analyses of used crankcase blended oils indicate that the chlor.-ester content is little changed in service. As an example, a V-8 Ford truck, operating with a load of 18,000-22,000 pound at an average speed of 40 miles per hour and an average distance of 300 miles per day, was run 4016 miles on a crankcase charge of 5 quarts of chlor.-ester blend, to which 5 quarts were added as make-up. At the end of this distance the crankcase oil showed an oil-soluble organic-chlorine content of 0.130 percent, as compared with the initial figure of 0.137 percent, indicating that the addition agent had been consumed at the same rate as the oil.

Effect on Physical Characteristics of the Oil

In general, the small quantity of an addition agent has little or no effect on the physical characteristics of the oil, but a few factors must be considered in the final selection of a product. It should be perfectly soluble at all temperatures, so that neither the cloud nor the pour test of the oil is raised. The more volatile products may depress the flash point, and in the case of volatile chlorinated hydrocarbons may give a peculiar bluish glow rather than a true flash. The material must not be water-soluble or tend to increase the emulsifying characteristics of the oil. As a rule, the ester type of compound has low viscosity and a high viscosity index, but is used in too small a quantity to make an appreciable difference in the mineral oil.

Toxicity

Neither a compounding agent nor its decomposition products should have any toxic or obnoxious—such as odorous, anaesthetic, or corrosive—characteristics. As an example, the animal and vegetable oil bases cannot be used because of the offensive odor from the decomposition products of the fixed oil. Some of the xanthates and phenolic compounds show excellent film-strength and oiliness characteristics, but have offensive odors which, in some cases, are nauseating. Relatively volatile products, particularly highly-chlorinated lighter hydrocarbons, are undesirable—both because of their loss through evaporation in service, and the possibility of harmful effects to the operator of a closed car.

Methyldichlorostearate has none of these objections. It is non-odorous and non-irritating. In three years of commercial use, the workmen handling both the ester and compounded oil have found it entirely harmless;

and, as previously discussed, it is non-volatile under the most severe operating conditions.

SUMMARY

The increased severity of the operating loads, speeds, and temperatures of the modern automotive engine have necessitated the improvement of crankcase oils. The true lubricating value or the ability to lubricate under severe or abnormal conditions may be improved by the use of a carefully-selected addition agent. The selection of such an agent cannot be accomplished with a single or limited group of laboratory tests, but must ultimately depend upon actual service tests on the road. A detailed study in the laboratory of all of the factors involved in lubrication is a valuable preliminary step. The various factors which must be studied are:

1. *Load-carrying capacity* is the ability to carry the highest possible load at the highest probable temperature with a minimum supply of oil for an indefinite period.

2. *Oiliness*—which is the ability of a lubricant to operate under boundary or thin-film conditions with low friction and resultant low heat formation.

3. *Metal wears*: The oil must not only carry high loads with low friction, but must do so without appreciable metal wear.

4. *Corrosiveness*: Neither the agent nor its decomposition products should be corrosive to any metal with which it will come in contact during distribution or service.

5. *Corrosion protection*: The product must not only be non-corrosive itself, but should form a strongly adsorbed film on metal surfaces which will protect them from the corrosive products of combustion and of oxidation of the mineral oil.

6. *Stability*: The addition agent must not only be stable under the highest temperatures reached, but it must not accelerate the oxidation of the mineral oil. It should act preferably as an inhibitor.

7. *Physical characteristics*: Its physical characteristics, such as volatility, flash point, pour test, solubility, etc., must not be detrimental to the required specifications of the mineral oil.

8. *Toxicity*: The addition agent must have neither toxic nor obnoxious characteristics.

The laboratory and road test data submitted show that all of these requirements can be secured by the use of a chemically-stable highly-polar compound such as the esters of chlorinated aliphatic acids and monohydric alcohols, specifically methyl-*a*, *a*-dichlorostearate.

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The Petroleum Refiner Views

Development of High-Speed Diesel Engine Fuels

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THE conventional Diesel engine, which has been in use for one-third of a century, has demonstrated its ability to operate upon fuels of almost every description. The modern high-speed Diesel, however, requires a carefully-prepared fuel for its successful operation.

The great variety of fuel specifications in vogue threatens to limit the widespread adoption of high-speed Diesels. In the present paper which was presented at the Sixteenth Annual Meeting, American Petroleum Institute, at Los Angeles, November 14, 1935, the authors point out that the costs of distribution of Diesel fuel will become excessive unless the Diesel builders and the consumer are able to agree upon a smaller number of grades.

It is suggested that advantage be taken of the existing distribution systems which have been set up for the distribution of household-burner fuels. If cooperation between the engine builder and the refiner is possible, the authors believe that household-burner fuels can be developed which will also be satisfactory for use in modern high-speed Diesel engines.

THE compression-ignition engine was invented in Germany in 1892 by Dr. Rudolf Diesel. During the past 35 years development of the engine has proceeded in an orderly fashion, until at the present day this type of equipment is recognized as one of our important forms of prime movers.

While many of the mechanical problems which were met in the gradual evolution of the Diesel engine have been solved by brilliant research and invention, many of the chemical and economic problems which originated with the demand for large quantities of Diesel fuel have been given but scant attention.

Dr. Diesel set himself to the task of developing an engine which might be operated upon fuels of the crudest sort. Hence, he was not faced with any difficulty in finding a large variety of fuels upon which his invention might be operated.

The large stationary and marine Diesels, following the path mapped out by their inventor, were of necessity designed to operate upon available fuels, since they were required to compete with the steam engine which employed low-priced coal or the cheaper bunker oils.

The development of the compression-ignition engine proceeded slowly during the first years of the present century, approximately 4,000,000 horsepower[1] of Diesel engines having been built between 1900 and 1932. During the past three years the field of usefulness of the compression-ignition engine has changed. Between 1932 and 1935 the American public became conscious of the possibilities of the compression-ignition engine, with the result that about 700,000 horsepower[1] additional of engines was created. The latter engines differ from their predecessors in one important respect: they are small, light-weight engines — the so-called high-speed Diesel engines.

The manufacture of thousands of the new type of prime movers immediately created a demand for a fuel which was adapted to the requirements of the new engines. The first Diesels of the high-speed type were forced to run upon whatever fuel was at hand; since, in most cases, the designers were so tied up with the problem of producing them as rapidly as they were demanded that little time was available for studying the fuel which they would be required to consume.

To protect themselves from certain injurious fuels which were responsible for failures of some of the earlier engines, the engine builders soon drew up fuel specifications which were, in effect, simply descriptions of a particular fuel which the factory had found to be satisfactory. This relatively unsatisfactory condition was remedied recently by a few of the builders through the adoption of more intelligent specifications, based upon actual investigations.

In 1932, however, the situation was still almost intolerable. At this point the American Society for Testing Materials stepped in with the aim of bringing the builder, the fuel producer, and the consumer together. This resulted in the ASTM Diesel Fuel Committee, which set up a tentative classification in 1934.

The society, continuing its investigation, considered the interlocking nature of the properties of petroleum in drawing up its tentative classification. The 1935 Diesel fuel classification of fuels for high-speed engines is shown in Table 1.

The fact that these classifications prepared by the

[1] From L. H. Morrison, *Diesel Engineering Handbook*, 7 edn.

society are now available would indicate that a satisfactory position had been reached. However, the refiner who is attempting to set up distribution facilities for Diesel fuels soon finds that this is not the case; and that while many of the consumers are demanding fuels which meet ASTM classifications, engine builders are specifying special fuel characteristics which are not covered by these classifications. To complicate the condition further, a fuel that meets the requirements of one engine builder may be found to be unsuitable by another builder.

TABLE I
Diesel Fuels
(ASTM Classification)
(Abridged)

	No. 1-D	No. 3-D
Flash point, ° F. (minimum)*	115 or legal	150
Pour point, ° F. (maximum)†	35	35
Viscosity, Saybolt Universal, at 100° F., sec.	32–50	32–70
Carbon residue (maximum), percent	0.2	0.5
Ash content (maximum), percent	0.02	0.02
Water and sediment (maximum), percent	0.05	0.1
Sulfur (maximum), percent‡	1.5	1.5
Cetene No.	50	40

* Minimum flash point, as stated or as required by local fire regulations, fire underwriters, or state laws.
† Lower pour points may be specified whenever required by local temperature conditions to facilitate storage and use, although it should not be necessary to specify a pour point of less than 0° F.
‡ For intermittent service.

In Table 2 are reproduced some of the latest engine-builders' specifications for high-speed Diesel fuel. Reference to the table will serve to show that no single fuel will meet all of the specifications.

A review of the listed engine-builders' specifications shows that it is practically impossible for the refiner to produce fuels to meet the demands of each engine builder. If it were feasible to produce a large number of fuels, each prepared to the specifications of one or two engine builders, the price of such fuels would be high because of high manufacturing and distribution cost coupled with small demand.

This is also a problem of the engine marketer; for a fleet operator may have two or more types of engines in his fleet, and he may not like to arrange for two or more kinds of fuel.

Not only must the agreement of specifications be considered, but the limits must be such as to permit quantity production of fuels. This point is illustrated graphically in Figure 1.

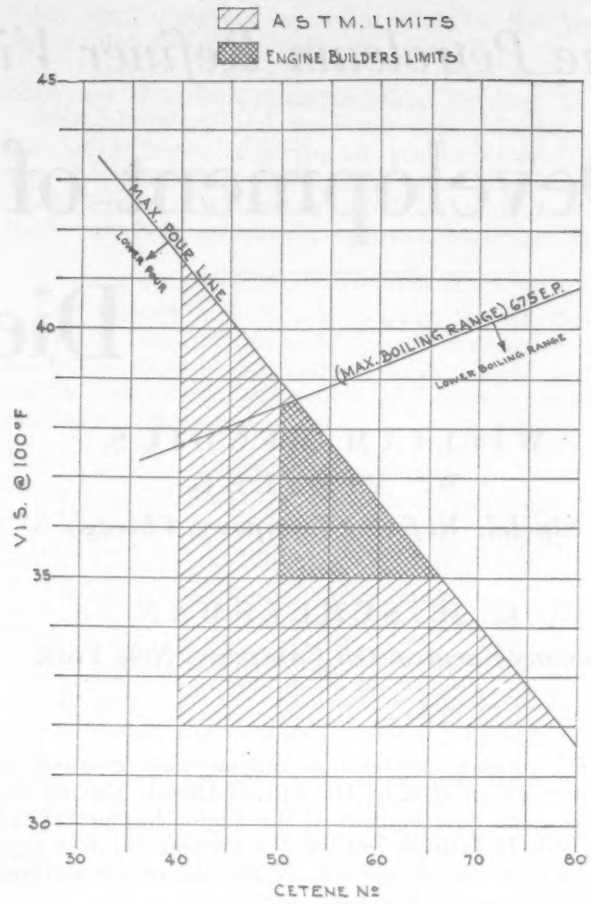

FIGURE 1

No attempt has been made to make this chart complete; however, it illustrates the point that when any one characteristic is limited, it also limits other characteristics. It can be seen that by changing the specifications away from those set up by the American Society for Testing Materials a quantity of refinery stocks is cast outside the usable range.

It is recognized that the designer of the aircraft Diesel may require a highly-specialized fuel which, of

TABLE 2
Diesel-Engine-Builders' Fuel Specifications

BUILDER	M	N	O	P	Q	R	S	T	U	V
Gravity, ° A.P.I.	....	....	....	30–35	26–29	....	26–36	22–34	24 or above	....
Viscosity, Saybolt Universal, at 100° F., sec.	35, min.	32	35, min.	35–40	35–40	35	34, min.	37	35–80	35, min.
ASTM Distillation in ° F.:										
Initial boiling point	....	....	....	....	....	....	....	....	....	....
10-percent point	....	....	....	....	....	....	460	....	460	....
90-percent point	....	....	....	....	....	....	675	....	675	....
End point	....	95 percent at 640	....	98 percent at 700, maximum	98 percent at 700, maximum	....	....	....	700	....
Recovery, percent	....	....	....	98	98 percent minimum	....	....	....	98 percent, minimum	98 percent, minimum
Sulfur (maximum), percent	2.0	....	0.7	0.5	0.5	2.0	1.0	0.5	0.75	0.5
Carbon residue (maximum), percent	0.25	0.5	....	0.03	0.03	1.0	....	1.0	0.1	0.25
Ash content (maximum), percent	0.01	....	....	0.02	0.02	0.02	....	0.5	0.02	0.02
Residue (maximum), percent	....	....	2.0 (open cup)	....	....	....	....	....	....	....
Btu. per lb.	....	....	....	....	....	....	....	18,500, minimum	....	....
Cetane No.	45, min.	40	50, min.	46–60	38–48	50, min. 70 heptane	50, min.	....	50, min.	50, min.
Critical-compression ratio	....	....	8.5, max.	....	....	....	8.5, max.	....	....	....
Diesel index	....	....	....	35–46	29–37	....	....	....	....	....
Water and sediment (maximum), percent	0.05	....	0.5	Trace	0.2	0.5	1.0	0.5	0.5	0.5

Pour Point: The fuel must flow at lowest atmospheric temperature at which engine is operated.
Flash Point: Flash point is not considered important by any of the builders, but most of them specify a minimum of 150° F., because this is the legal limit of some states for fuels used in building.

TABLE 3
Burner Fuels
(ASTM Tentative Specifications for Fuel Oils, D396-34T)

	No. 1	No. 2	No. 3
Flash point, ° F.	100–150 or legal	110–190 or legal	110–200 or legal
Pour point, ° F.	15*	15*	15*
ASTM Distillation in ° F.:			
10-percent point	420, maximum	440, maximum	.....
90-percent point	.....	620, maximum	620, minimum†
End point	600, maximum	600, minimum	.....
Viscosity, Saybolt Universal (maximum), at 100° F., sec.	.....	.....	70
Carbon residue (maximum), percent	0.02	0.05	0.15
Water and sediment (maximum), percent	0.05	0.05	0.1
Sulfur (maximum), percent	0.5	0.5	0.75

* Lower or higher pour points may be specified whenever required by conditions of storage or use. However, these specifications shall not require a pour point lower than 0° F.

† This requirement shall be waived when the carbon residue is more than 0.07 percent and less than 0.15 percent.

TABLE 4
Commercial No. 1 Burner Fuels—Laboratory Inspection Data—Midwest Source

SAMPLE NO.	1	2	3	4	5	6	7	8	9	10	11	12
Gravity, ° A.P.I.	41.7	39.3	37.2	41.1	39.3	41.9	43.0	43.0	40.0	40.0	38.0	40.9
ASTM Distillation in ° F.:												
Initial boiling point	357	310	358	349	347	323	364	360	330	350	364	380
10-percent point	397	403	392	392	416	410	377	400	385	420	384	426
50-percent point	436	454	424	428	464	454	420	435	467	445	421	482
90-percent point	489	508	461	484	517	498	466	485	525	475	466	537
End point	545	564	504	546	565	534	498	550	590	500	503	560
Flash point, Pensky-Martens, ° F.	142	128	144	138	142	130	115	...	125	117	...	162
Color	1½+	1+	1+	1½+	1+	1—	Prime White	...	+16	+16	0—1	6
Doctor text	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	...	...	O.K.	O.K.	...	N.G.
Water and sediment, percent	None	None	None	None	None	None	None	...	...	...	...	...
Carbon residue, percent	0.013	0.024	0.060	0.022	0.009	0.012	0.010	...	0.001	...	...	0.010
Sulfur, percent	0.01	0.48	0.31	0.11	0.10	0.01	...	...	0.084	0.028	...	0.060
Aniline No., ° C.	64.7	61.7	47.5	60.6	63.0	67.8	...	...	...	...	...	...
Pour point, ° F.	Below —10	Below —10	Below —10	Below —10	Below —10	Below —10	—25	...	Below 0	—40	Flow at 25	0
Viscosity, Saybolt Universal, at 100° F., sec.	33	33	31	32	33	33	30	...	33	32.5	...	34
Cetene No.	53	51	39	50	53	54	55.9	...	55.3	44.9	...	58.5

TABLE 5
Commercial No. 2 Burner Fuels—Laboratory Inspection Data

SOURCE	MIDWEST								EAST COAST				
Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Gravity, ° A.P.I.	38.0	39.0	37.0	35.0	36.0	35.6	32.9	37.2	36.4	35.4	35.4	31.7	38.0
ASTM Distillation in ° F.:													
Initial boiling point	375	375	370	375	375	330	374	327	373	369	358	375	375
10-percent point	424	425	440	405	405	414	437	447	426	427	425	431	424
50-percent point	501	501	512	430	...	459	473	530	476	485	477	493	501
90-percent point	597	601	590	464	475	518	528	604	548	574	560	570	597
End point	647	656	650	538	600	606	621	638	610	634	626	653	647
Flash point, Pensky-Martens, ° F.	164	130	170	170	170	140	174	148	164	152	156	154	164
Color	Dark, 1	0—1	1½	...	...	4+	4—	2—	Dark, 2	Light, 2	Dark, 2	Dark, 3	Dark, 1
Doctor test	...	...	...	...	...	O.K.	O.K.	O.K.	...	...	...	...	...
Water and sediment, percent	Trace	None	...	...	...	None	None	None	Trace	Trace	Trace	Trace	Trace
Carbon residue, percent	0.01	0.02	0.02	0.006	...	0.033	0.06	0.03	0.012	0.018	0.01	0.01	0.01
Sulfur, percent	0.08	...	0.25	0.24	0.3	0.16	0.31	0.12	0.24	0.63	0.28	0.28	0.08
Aniline No., ° C.	...	...	...	...	...	51.0	47.5	71.7	57.2	60.6	56.1	56.5	68.8
Pour point, ° F.	0	—25	0	Below 0	...	Below —10	Below —10	Below —10	Below 0	Below 0	Below 0	Below 0	0
Viscosity, Saybolt Universal, at 100° F., sec.	35	33	36	32	32	33	35	33	34	35	34	36	35
Cetene No.	54.9	53.9	54.3	46.4	48.3	46	43	56	49	52	48	44	55

TABLE 6
Commercial No. 3 Burner Fuels—Laboratory Inspection Data—Midwest Source

SAMPLE NO.	1	2	3	4	5	6	7	8	9
Gravity, ° A.P.I.	32.0	33.0	26.4	31.9	36.7	26.8	34.0	30.4	39.0
ASTM Distillation in ° F.:									
Initial boiling point	296	375	346	287	310	354	410	372	400
10-percent point	431	432	437	431	428	444	445	418	...
50-percent point	473	487	516	473	487	530	503	498	...
90-percent point	532	595	620	536	553	637	605	673	...
End point	638	679	704	637	618	734	694	700	625
Flash point, Pensky-Martens, ° F.	120	172	154	116	146	162	160	170	...
Color	4½+	3½+	8+	4½+	3+	8+	3	8	...
Doctor test	O.K.	O.K.	Too dark	O.K.	O.K.	Too dark	...	...	...
Water and sediment, percent	None	None	None	None	None	Trace	...	...	...
Carbon residue, percent	0.096	0.056	0.044	0.035	0.053	0.070	0.050	0.070	...
Sulfur, percent	0.22	0.65	0.60	0.24	0.14	0.59	...	0.400	...
Aniline No. ° C.	44.4	54.3	37.9	44.5	61.5	42.7	...	...	...
Pour point, ° F.	Below —10	Below —10	—5	Below —10	Below —10	—10	—25	0	...
Viscosity, Saybolt Universal, at 100° F., sec.	34	36	37	34	35	34	34	37	38
Cetene No.	40	46	36	40	52	40	47	44	...

TABLE 7
Basic Straight-Run Diesel Fuels

CRUDE	BARRELS PER DAY			
	Mid-Continent	Pennsylvania	Gulf Coastal	California
Crude Capacity*				
1. East Coast	609,000	.....	.....	.....
2. Appalachian	.....	154,150	.....	.....
3. Indiana, Illinois, Kentucky	423,820	.....	.....	.....
4. Oklahoma, Kansas, Missouri	445,870	.....	.....	.....
5. Inland Texas	328,244	.....	.....	.....
6. Texas Gulf Coast	.....	.....	536,500	.....
7. Louisiana Gulf Coast	.....	.....	139,000	.....
8. North Louisiana and Arkansas	79,800	.....	.....	.....
9. Rocky Mountain	.....	.....	.....	81,975
10. California	.....	.....	.....	755,210
Total	1,886,734	154,150	675,500	837,185
Grade Run†				
	463,000 (1)	98,000 (2)	511,000 (6)	41,000 (9)
	336,000 (3)	.....	110,000 (7)	431,000 (10)
	249,000 (4)	.....	.....	.....
	93,000 (5)	.....	.....	.....
	44,000 (8)	.....	.....	.....
Total	1,185,000	98,000	621,000	472,000
Percent of capacity	62.8	63.5	90.0	56.4

SAMPLE:

	A	B	A	B	A	B	A	B
Potential Gas Oil Yield‡								
Yield, percent	30	29	27	32	26.0	38.0	20.0	27.0
Characteristics:								
Gravity, ° A.P.I.	39.3	37.0	44.0	40.0	28.8	25.2	38.0	34.0
ASTM Distillation in ° F.:								
Initial boiling point	350	400	350	400	350	400	350	400
50-percent point	465	523	464	543	505	573	475	586
End point	600	700	600	700	600	700	600	700
Sulfur, percent	0.085	0.13	...	...	0.09	0.12	0.026	0.052
Pour point, ° F.	—10	+5	30	40	Below —25	Below —25	—20	0
Viscosity, Saybolt Universal, at 100° F., sec.	35	39	33	37	34	44	34	38
Cetene No.	61.5	62	66	65	43	42	58	56

* From Bureau of Mines Information Circular No. 6807 (Aug., 1934) as of Jan. 1, 1934.
† Average of A.P.I. weekly refinery statistics.
‡ From assay data of individual crudes.

course, will be supplied at a premium price. The marketer of the automotive Diesel, however, is in direct competition with other types of power producers, and the main sales point is low fuel cost. For this reason it appears that in the future the conventional high-speed Diesel of the automotive type must be designed to be operated upon the fuel which is cheapest and, if possible, already widely distributed, to avoid adding a separate distribution charge.

Diesel fueling is faced with two distinct problems: 1, to find widely-distributed fuels for use in engines now operating; 2, to develop for the future an engine and a fuel which, when employed together, will produce power at the lowest possible cost.

Examination of the characteristics of currently-produced burner fuels which are available in most districts of this country reflects a possible solution of the first problem. There is reproduced, in Table 3, the ASTM specifications covering No. 1, No. 2, and No. 3 burner fuels. In Tables 4, 5, and 6 actual laboratory-inspection data of a representative number of burner fuels marketed by competitive refiners during 1934 and 1935 are given. Careful examination of these data will show that like-grouped fuels are reasonably uniform.

The No. 1 fuels generally have a cetene rating between 50 and 55; they have low viscosity of about 32 seconds, and they have a relatively low boiling range.

The No. 2 fuels have a somewhat higher boiling range; a viscosity range from 32 to 36, and cetene ratings approximating 45 to 50.

The No. 3 fuels approach Diesel fuel boiling-range specifications; their viscosity ranges from 34 to 37, and their cetene rating may be classified as 40 to 45.

It is appreciated that some of these products do not meet every requirement of any single grade; e.g., one sample of No. 1 burner oil had a Saybolt viscosity of 30 seconds. They all appear to be quite satisfactory with respect to carbon residue and sulfur. Their pour points are 0°F., or lower. They have become fairly well stabilized after several years of experience, and are not likely to change materially in the immediate future.

It has been previously pointed out that the petroleum industry is not able to develop and market as many different Diesel fuels as there are leading engine builders. Review of the builders' specifications shows that it is hopeless at the present time to market a single fuel which will meet even the majority of these specifications. Therefore, it seems necessary that the specifications be adjusted so that they can be met with a reasonable number of fuels.

It has been fairly well proved that practically all high-speed Diesels can be operated satisfactorily with a market supply of but two grades: one a light distillate, and the other somewhat heavier—the selection of which of these fuels to use to be left, to some extent, to the consumer. After all, it will not be many years before the consumers will have some very definite ideas concerning the type of fuel to use.

It seems that the present supply of burner fuels offers a logical source for the present Diesel fuel market. It must be admitted that some of these burner fuels, although excellent for their intended purpose, possess cetene ratings too low for practical use. These would automatically be excluded from the Diesel fuel market, which would have little or no influence on their original market. The stocks acceptable for Diesel usage (those having cetene ratings of approximately 40 and higher) can be readily supplied on the basis of current Diesel

TABLE 8
Basic Cracked Diesel Fuels

CRUDE	BARRELS PER DAY					
	Mid-Continent	Pennsylvania	Gulf Coastal		California	
Crude Run*	1,185,000	98,000	621,000		472,000	
CRACKED FUEL OILS	**A**	**B**	**A**	**B**		
Yield, percent of crude (approximate)	5–30	1–10	10	3	35	10
SAMPLE:						
	A	**B**	**A**	**B**	**A**	**A**	**B**
Gravity, ° A.P.I.	36.8	28.4	40.1	32.1	28.2	32.4	16.7
ASTM Distillation in ° F.:							
Initial boiling point	368	368	367	360	362	425	392
10-percent point	416	437	404	418	432	445	470
50-percent point	468	475	470	486	468	476	523
90-percent point	540	536	529	548	504	538	694
End point	586	586	599	636	526	525	721
Sulfur, percent	0.139	0.262	...	...	0.065	0.25	0.28
Pour point, ° F.	Below —15	Below —15	0	0	Below —15	0	...
Viscosity, Saybolt Universal, at 100° F., sec.	33.4	33.8	32.4	33.6	34.4	...	...
Cetene No.	47.5	35	54.8	43.3	20	...	...

* Refers to Table 7.

fuel consumption, without materially affecting their burner fuel market. It is also reasonable to expect that some alteration in the characteristics of many of these fuels may take place during the next few years to accommodate both Diesel and burner fuel requirements. Acceptance of these recommendations by the Diesel engine builders and operators would be of material aid in stabilizing present conditions.

On an economic basis, the development of the Diesel fuel of the future should be guided by the stocks which the refiner is tooled to make without incurring additional cost. These so-called basic stocks have been divided into straight-run and cracked products. These, in the majority of cases, are distillate oils, and can be classed as clean—which is quite necessary for continuous and satisfactory Diesel operation. The burner fuels of today are generally derived from these cracked products or their blends with straight-run stocks. This would indicate that the engine manufacturers may anticipate a fuel standard not far removed from current burner fuels.

Characteristics and yields of straight-run basic Diesel fuels are presented in Table 7. Likewise, data for basic cracked fuels are given in Table 8. These data are by no means exhaustive; they are, however, considered fairly representative.

The straight-run fuels, with the exception of those derived from Gulf Coastal crudes, are shown to have cetene ratings of 55 to 65, with pour points ranging from —10°F. to 40°F. Generally, increase in cetene rating is accompanied by increase in pour point. These fuels embrace viscosities from 33 to 39.

The cracked fuels also, except those from Gulf Coastal and some California crudes, have cetene ratings ranging from 35 to 55, pour points of 0°F., or less, and viscosities from 32 to 34.

While engine builders, and probably some major consumers, are familiar with the fact that fuels of high cetene rating must command a higher price than fuels of low cetene rating, they may not be as well aware of the influence of other factors upon fuel cost. Too high a cetene requirement will eliminate the greater portion of cracked Diesel fuels. Virgin oils must supply the demand.

The use of solely virgin oils introduces the pour problem for many crudes. Dewaxing operations are expensive. Year-round Diesel fuel specifications which demand 0 pour point are fairly common. Since the pour point of a fuel is of little importance during the summer months, the demand for 0 pour point during warm weather results in an economic waste. A dewaxing charge may be avoided by including in the specifications separate pour limitations for winter and summer usage, preferably influenced by climatic conditions in the zone of consumption.

Virgin oils routed to Diesel consumption must also compete with the value of this stock as a source of high-anti-knock cracked gasoline. Prices of the respective fuels determine the economic balance.

Material narrowing of the boiling-point specifications would, by virtue of decrease in yield and added refinery-distillation processing, add to the refinery costs.

It is estimated that refinery costs alone may be increased by as much as one cent per gallon by imposing Diesel fuel restrictions similar to those noted above.

The petroleum industry has established substantially nationwide distribution for two classes of fuel products, viz., motor gasoline and burner fuels. As Diesel fuel is not being marketed in any appreciable quantity for passenger or light truck use, the use of the service station outlet is impractical. The present demands as bulk sales, in small or large volume, make it necessary for the refiner either to market Diesel fuel through its present burner oil system or to set up an entirely new distribution system.

TABLE 9
Estimated Distribution Costs for City of 100,000 Population*

SYSTEM	Present Burner Fuel (Cents Per Gallon)	Special Diesel Fuel (Cents Per Gallon)
Occasional purchase of 50-gal. drums—none returnable	....	5.0
Daily tank truck deliveries from 10,000-gal. storage	0.50	1.75†
Tank car deliveries to customer's own tanks (exclusive of freight)	0.20	1.50†

* The above estimates have been prepared for purposes of discussion only. The figures do not represent actual costs.

† The higher distribution cost incurred by the installation of a distribution system for diesel fuels alone, as compared to utilization of the present burner fuel system, is due both to additional investment and to lower volume turn-over.

Some Characteristics of Internal Combustion Engines *When Operating on* Butane-Air Mixtures

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A THOROUGH understanding of the relation of the independent variables to the operating characteristics of internal-combustion engines is required if the most economical utilization of the fuel is desired. Most exacting data are essential if the variables are to be separated. The Department of Mechanical Engineering at the University of California has planned an engine-test program which it is hoped will, when complete, answer many questions relative to the relation between the independent and dependent variables in internal-combustion engines.

The results so far obtained indicate: 1, that the friction horsepower increases at a decreasing rate as the compression ratio is increased, and that with the use of a light crankcase oil partial lubrication is evidenced; and, 2, that the volumetric efficiency, to which the torque developed is proportional, decreases with increased compression ratio, spark advance, fuel-air-mixture ratios approaching those for complete combustion, and is a function of valve timing.

Butane as a motor fuel shows many advantages over liquid fuels. The homogeneous mixture obtainable with a gaseous fuel increases the economy in multi-cylinder engines through the more uniform mixture distribution to the individual cylinders, particularly when the engine is operating relatively cold at normal atmospheric temperatures. For most economical utilization of the fuel it is important to adjust accurately the carburetor and spark settings in order that maximum economy at the part-throttle settings for average operation may be obtained.

This paper was presented at Sixteenth Annual Meeting, American Petroleum Institute, at Los Angeles, November 14, 1935.

LITERATURE presents a wealth of information relative to the operating characteristics of internal-combustion engines. One can find articles explaining the influence of any desired variable, in design or operation, on engine economy and output. Since these various tests are not performed under similar conditions, or on similar equipment, and since the conditions of test are not always fully stated, it becomes difficult at times to correlate the results. Hence, if one is aware of the relation a given variable has to another, one is still at a loss in many instances as to what the results might have been if a third, fourth, or nth variable had been considered. In order more definitely to establish the inter-relation of the many variables to be given consideration, an engine-test program was established, in the spring of 1932, in the Department of Mechanical Engineering at the University of California at Berkeley. This program is to cover as completely as possible the many operating characteristics, fundamental design characteristics, the advantages of various fuels, and particularly the relation of one to the other. In order satisfactorily to correlate the data obtained from engine tests, it is necessary to conduct all experiments on one piece of equipment, and thus eliminate such variables as may enter due to design, e.g., the induction system.

LABORATORY EQUIPMENT

The experimental station (Figure 1) consists of a single-cylinder variable-compression engine with a 3 1/16-inch bore and 4½-inch stroke. The compression ratio can be varied between the limits of 3.5 to 8.7. The exhaust and intake cams are so arranged on the camshaft that it is possible to vary their settings independently. During the present tests the valve timing is as follows:

Intake opens 8 deg. after top dead center.

Intake closes 44 deg. after bottom dead center.

Exhaust opens 43 deg. before bottom dead center.

Exhaust closes 6 deg. before top dead center.

The ignition system on the engine is so designed that on the exhaust stroke a spark passes between a pointer and a scale graduated in "degrees before and after top dead center," from which the spark timing on the compression stroke may accurately be ascertained. The cooling system is a self-contained unit in which distilled water is circulated from the cylinder jacket through a condenser cooled with tap water. In this way possible deposits in the water jacket are reduced to a minimum. The rate of water flow is closely regulated with a micrometer valve. Water temperatures are read on thermometers on the intake and discharge sides of the water jacket. Electric heating coils for the mixture are mounted on the intake manifold between the carburetor and the engine.

The engine is loaded with a five horsepower shunt generator mounted on bearing pedestals. The rotation of the field frame is constrained by an arm connected to a torsion balance from which the load may be determined to within 0.01 pounds. The load is controlled with heating elements which may be switched into the armature circuit in combinations ranging from 1 to 20, while close adjustments of speed are made with a field rheostat.

The air taken into the engine is drawn through a

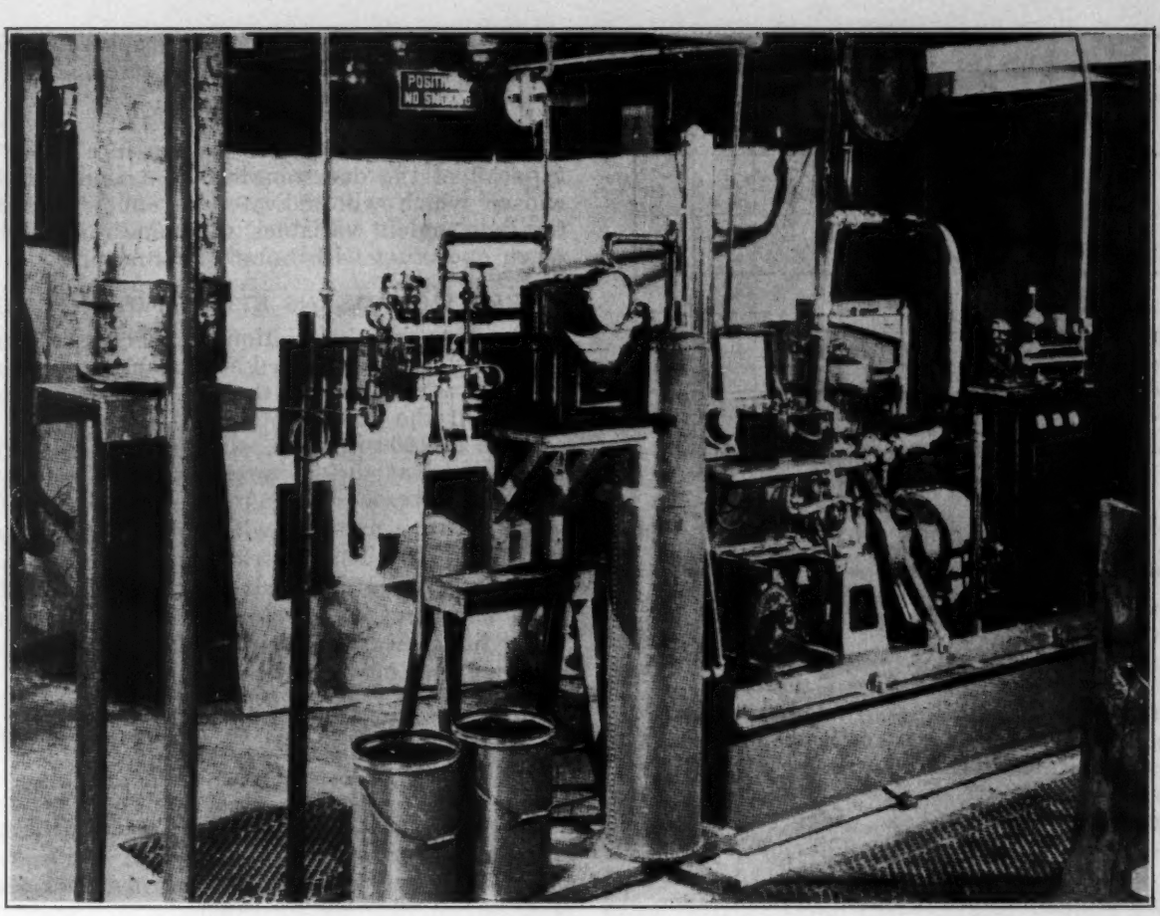

FIGURE 1

A General View of the Variable-Compression Engine Equipped to Operate on Butane, Natural Gas, or Gasoline.

0.462-inch diameter bell-mouthed orifice in one end of a 60-gallon drum used as a surge tank, the other end of which is covered with an elk skin to reduce pressure variations. The drop of pressure across the orifice is measured with a slant-tube manometer using water as an indicating medium. Knowing the pressure drop across the orifice, the atmospheric temperature, barometric pressure, and humidity, the weight of air admitted to the engine in unit time may be determined.

The gasoline-fuel system consists of two metal containers connected by a two-way stop-cock to a graduated pipette, so that the rate of fuel flow to the carburetor may be timed and the weight of fuel consumed per unit of time calculated. In order to eliminate the use of two induction systems when using gaseous fuels and liquid fuels, respectively, a line for the liquid fuels is led from the needle valve of a 1¼-inch Schebler carburetor to the venturi of the carburetor for gaseous fuels—thus permitting the use of one induction system for all fuels, and eliminating one variable when comparing fuels.

The liquefied gaseous fuels are led from the storage tanks through a pressure-reducing valve to a heater. The heater is supplied with hot water from a water heater, so that better temperature control of the fuel is obtained than if the hot water were taken from the water jacket of the engine. From the heater the fuel passes through a liquid trap, and through a pressure regulator. A system of valves permits the use of any one of the various pressure regulators mounted on the panel. From the pressure regulator the gaseous fuel passes through a five-light gas meter calibrated to 0.01 cubic feet, then to a 30-gallon drum which serves as a surge chamber for the fuel before it enters the carburetor. Pressures in the fuel system are measured on the low-pressure side of the fuel regulator, in the surge tank, and in the intake manifold where it attaches to the engine. The later pressure is measured with a mercury manometer, which is connected to the intake manifold with a line containing two light check valves—thus permitting the determination of the maximum manifold depression. Temperatures of the water entering and leaving the fuel heater, of the fuel at three points between the heater and the engine, of the intake and exhaust mixtures, the crankcase oil, and the atmosphere are measured.

A sampling tank is connected to the exhaust line for obtaining samples of the exhaust gases for analysis with an Orsat apparatus.

TESTING METHODS

All tests are scheduled in such manner that all but one of the independent variables are accurately controlled. The independent variables are compression ratio, throttle position, cooling-water temperature, mixture ratio, mixture temperature, spark setting, and engine speed. In order to obtain the steady-state temperature distribution throughout the engine, it has been found necessary to operate the engine for at least 1½ hours before observations are begun. For the period of operation preliminary to the record-

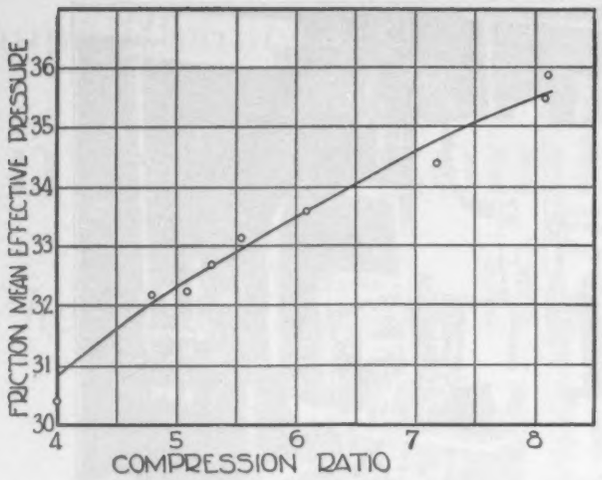

FIGURE 2

The Variation in Friction Losses as a Function of Compression Ratio. Engine at Operating Temperatures and Running at a Speed of 1,000 R.P.M.

ing of data, a Midgley indicator is used for the adjustment of the carburetor. No results are recorded from the indicator, since it is realized that even with the most accurate indicating system it is doubtful whether the results are of any practical value when accurate data are sought.[1] In order to hold conditions as closely in a state of equilibrium as possible when a test is in progress, the variables most easily controlled are maintained constant. For instance, the spark adjustment once set will not vary to any extent with adjustments in other variables. Therefore, for a given speed, spark setting, throttle position, and operating temperature, the mixture was varied for the range of combustibility. This procedure was followed for the various spark settings, compression ratios, and speeds at which the engine was operated. In order to check the condition of the engine, repeat tests were made and compared with results obtained shortly after the engine was overhauled and tuned. These tests included runs of compression pressures as a function of speed and compression ratio. With this procedure it was found that crossplots of the data would permit the separation of the variables and yield gratifying results.

The crankcase oil is changed approximately every 100 hours of engine operation, and analyzed for characteristics which might be related to the particular fuel which has been in use during that period.

When operating at part-throttle conditions it has been found desirable, in order to obtain accurate adjustment, to refer all throttle positions to the pressure drop in the air across the intake orifice. The results from such tests are then referred to the quantity of air taken into the engine per hour, rather than to throttle position.

In order to determine the friction horsepower by motoring the engine and yet obtain the results at conditions simulating as closely as possible the actual operating conditions, the following procedure was followed: At the end of a day's run, which had been conducted at a given speed and compression ratio, the balance on the dynamometer was loaded with weights approximating as closely as possible the friction load of the engine. The ignition circuit then was opened and the generator thrown over to the motor circuit. In this manner it was possible to obtain the engine-friction load before any appreciable change in operating conditions could be effected.

TEST RESULTS

Since it is impossible to present in a paper of this type all of the data obtained, only such have been chosen which will indicate the effect of certain of the independent variables and some results obtained when operating with butane-air mixtures.

FRICTION MEANS EFFECTIVE PRESSURE

The data for the friction mean effective pressure (Figure 2) were obtained at various times when the engine was shut down, thus insuring operating conditions at the instant of test. These results are at a speed of 1000 r.p.m., cooling-water temperature of 180°F., and at the compression ratios indicated. A definite decrease in the rate of change of friction mean effective pressure with increase in compression ratio is noted. This fact has also been indicated by other experimenters,[2] and may be explained as a phenomenon of lubrication and the reaction between the cylinder wall and piston. The reaction of the cylinder wall on the piston is expressed by:

$$F = (m\omega^2 n^2 A_n \cos n\theta + P) \tan \phi \qquad (1)$$

where: F = the reaction between the cylinder wall and piston, in pounds.

m = the mass of the reciprocating parts.

ω = the angular velocity of the crank.

n = the harmonic of the inertia force under consideration.

A = a constant, dependent upon the crank length and connecting-rod length.

θ = the angle between the crank and center line of the engine at the instant considered.

P = the total pressure acting downward on the piston.

ϕ = angle between the connecting rod and centerline of the engine.

Applying this expression to the case at hand, and considering only the average force F over the stroke, all values in the above expression are constant except the pressure, P, which is a function of the compression ratio. However, since P varies as approximately the 1.3 power of the compression ratio, the rate of change of friction mean effective pressure should increase with compression ratio rather than decrease. The variation of the coefficient of friction μ with the criterion ZN is well known. Applying this to the case under consideration where the speed is contsant, the variables, Z, the viscosity of the oil at operating temperature and the

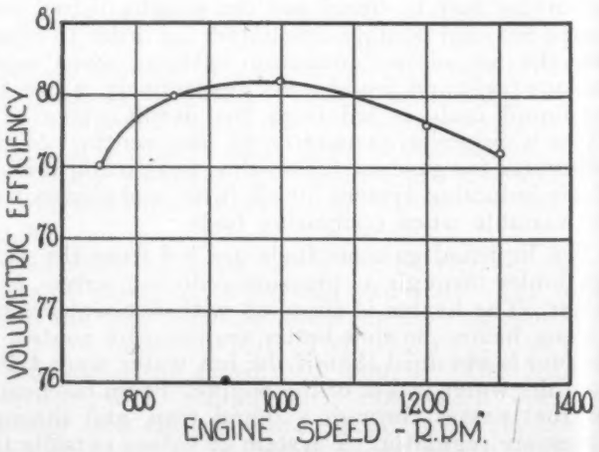

FIGURE 3

The Effect of Valve Timing on Volumetric Efficiency.

unit load p, the reaction between the cylinder wall and the piston, need only be considered. A decrease in the ratio $\frac{Z}{p}$ reduces the coefficient of friction μ until solid friction obtains. As the compression ratio is increased, the pressure, p, likewise increases and decreases the film thickness and, thereby, the coefficient of friction.[3] The viscosity is decreased at the higher compression ratios due to the increase in the gas-film-transfer factor which permits an increase in the rate of heat flow to the oil film. The film-transfer factor is given by:[4]

$$f_g = 0.0277 \sqrt[3]{P^2 T} (1+0.0063w) \text{ B.T.U./°F/Ft}^2\text{/hr.} \quad (2)$$

where: P = the gas pressure in the cylinder, lb. per sq. in., absolute.
T = the absolute temperature.
w = mean piston speed, ft. per min.

It is to be noted in this relation that the gas-film-transfer factor depends more on the pressure than on the temperature, although an increase in either variable tends to increase the final result. The piston velocity, w, is constant, and does not enter the problem under consideration. The heat interchanges are periodic. The temperature variations on the water side of the cylinder have been found to be negligible[5] due to the fact that the film resistance on the water side is not appreciably reduced with the small increase in the average rate of heat flow to the water with increase in compression ratio.

When motoring the engine until steady-state temperature distribution was obtained, it was found that the friction mean effective pressure was approximately 10 percent lower than that obtained by the methods described above. This would indicate that for at least a part of the stroke, where the pressure between cylinder wall and piston was relatively high, a region of partial lubrication might exist.

VOLUMETRIC EFFICIENCY

For the ideal engine, one having a mechanical efficiency of 100 percent, the torque is a function of the charge volume. For enonomical utilization of fuels and maximum power, the charge volume, or volumetric efficiency, should be as large as possible. It, therefore, becomes important to analyze the variables which may have a bearing on this characteristic. The volumetric efficiency here considered may be defined as the ratio of the quantity of combustible mixture drawn into the cylinder per stroke to the quantity which would fill the swept volume, both at the same conditions of temperature and pressure. It is important in this connection to give due consideration to the volume of fuel added to the air which, if neglected, may result in errors as high as six percent.

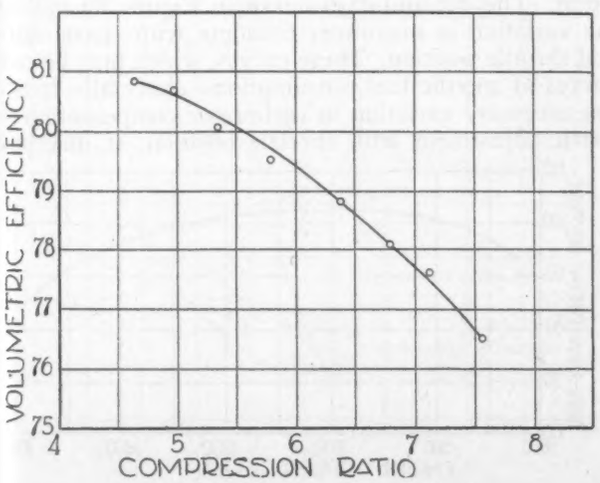

FIGURE 4

The Effect of Compression Ratio on Volumetric Efficiency at Engine Speed of 1,000 R.P.M.

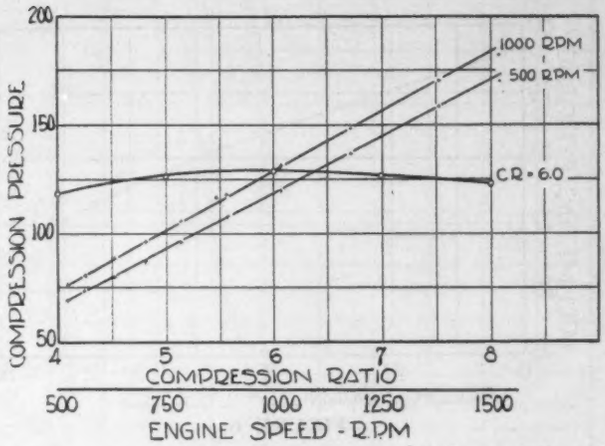

FIGURE 5

Compression Pressures as a Function of Compression Ratio and Engine Speed when the Engine is Motored Cold.

The relation between volumetric efficiency and engine speed (Figure 3) is well known, and may be definitely correlated with the valve timing and the characteristics of the induction system. The data for Figure 3 were obtained with constant compression ratio, mixture ratio, spark setting, cooling water, oil, and intake temperatures. Hence, the only dependent variables are the volumetric efficiency and the torque as a function of engine speed.

The effect of compression ratio on volumetric efficiency (Figure 4) was obtained by holding all independent variables constant except the compression ratio. Another method of obtaining these results is by cross-plotting the data obtained in the tests described above. This phenomenon may be explained to some extent by the fact that, when the clearance volume is large, the heat transferred to the walls of the combustion chamber will decrease the volume appreciably more than when the clearance volume is small—partly because the temperature of the residual gas is lower in the later case. This explanation, however, does not clarify the whole phenomenon, as indicated by calculation of existing conditions.[6] Hence, to justify the further decrease of volumetric efficiency with increase in compression ratio, equation (2) is applicable — which shows that the gas-film transfer factor is increased with the increased existing pressures (Figure 5) and temperatures. This allows an increase in heat flow to the cylinder wall, with a consequent increase in oil and wall temperatures. The periodic heat interchange between cylinder wall and cylinder contents heats the fresh charge on the intake and compression strokes, and thus reduces the volumetric efficiency.

A similar explanation holds for the effect of spark advance before top dead center (Figure 6). These data were obtained by cross-plotting the results of tests where all dependent variables except spark setting were held constant. From first considerations it might appear that the volumetric efficiency should decrease with retarded spark due to the high exhaust temperatures. However, the mean temperature throughout the stroke is increased with advanced

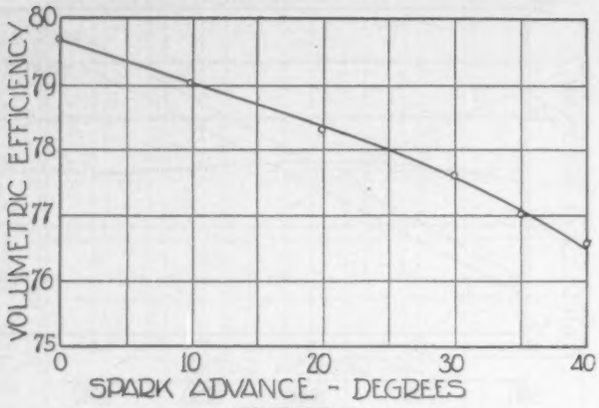

FIGURE 6

The Effect of Spark Advance on Volumetric Efficiency when Operating at Constant Speed, Constant Compression Ratio, and Constant Mixture Ratio.

spark setting; likewise, the mean gas pressure throughout the stroke is increased with advance in the point of ignition. Referring again to equation (2), it is noted that the gas-film transfer factor is increased—and, with it, as before, the rate of heat flow to the incoming fresh charge from the cylinder wall, oil and gas films.

With liquid fuels the volumetric efficiency is affected by mixture ratio because of evaporation. With gaseous fuels (Figure 7) this is hardly the case—and again the results obtained may be ascribed to the phenomenon indicated by equation (2). The decrease in volumetric efficiency as the mixture ratio is increased to the point of a theoretically-correct ratio for complete combustion is most probably due to a rise in the temperature of the cylinder walls, head, and piston—with an accompanying rise in mean pressure throughout the cycle. An increase in mixture ratio beyond the theoretical value for complete combustion will increase the average volumetric heat of the cylinder contents, and so reduce the flame temperature and that of the cylinder walls and the piston as well as the mean pressures. Hence, in this case again the variation in volumetric efficiency may be ascribed to a variation in the gas-film transfer factor.

ENGINE PERFORMANCE WHEN OPERATING WITH BUTANE-AIR MIXTURES

The use of gaseous fuels for internal-combustion engines, in stationary and transportation equipment, is becoming more extensive.[7] The advantages of such fuels over liquid fuels have been demonstrated in many instances.[8] One of the more important fuels under consideration at the present time is butane. With the use of butane as a fuel it is possible to increase the compression ratio of the engine appreciably over that allowable when operating with gasoline.[9] The results of such a change are too well known, and need not be dwelt on at any length. When the variable-compression engine was converted to the use of butane-air mixtures it was found that the economy for gasoline-air mixtures was higher at the same compression ratio than when operating with butane-air mixtures. These results are not found in equipment on the road, where better economy is always claimed for butane. This contradiction is evident if the difference in homogeneity between a gaseous mixture and an air-vapor mixture is considered. The more homogeneous mixture which obtains when operating with butane permits more uniform distribution of mixtures in the different cylinders of multi-cylinder engines, thus dividing the load developed more equally. It is obvious that, with such results, gaseous fuels can show an advantage over liquid fuels.

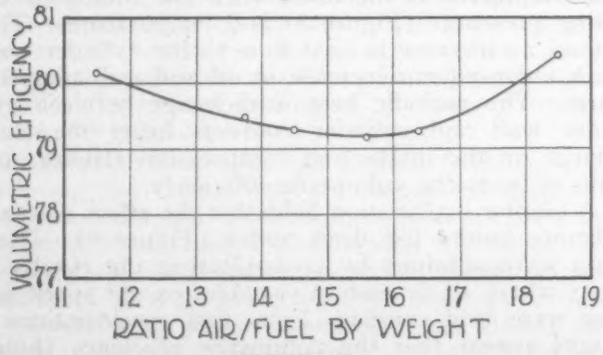

FIGURE 7

The Effect of Mixture Ratio on Volumetric Efficiency when Operating at Constant Speed, Constant Compression Ratio, and Constant Spark Setting.

The output of the engine was found to be higher for the same conditions of operation when operating with butane-air mixtures than when operating with gasoline-air mixtures.[9] These results were, in general, due to the type of carburetors required for the different fuels—the venturi required for gasoline being smaller at the throat than the venturi required for gaseous fuels. This increased restriction resulted in an appreciable decrease in brake mean effective pressure (B.M.E.P.). Later tests, in which one common induction system was employed, did not show an appreciable variation for similar conditions of operation.

The volumetric efficiency is also influenced by speed, due to valve timing. The effect of volumetric efficiency on B.M.E.P. is evident from a comparison of Figure 8 with Figure 3. The data for Figure 8 were obtained at constant compression ratio, with spark setting and mixture ratio for maximum B.M.E.P.

Figure 9 and 10 show the effect of mixture ratio, spark setting, and throttle position on the performance of the engine with butane-air mixtures. Some of these data were taken with various conditions of battery-terminal voltage to determine whether the energy in the spark would indicate any appreciable change in engine performance. It was concluded from these investigations that the spark intensity within the test limits imposed did not increase or decrease the power developed after the engine was warmed. The dot-and-dash curve in Figure 9 indicates the variation of maximum economy with variations in mixture ratio and throttle position. The dot-and-dash curve in Figure 10 indicates the variation in maximum economy with spark setting and throttle position. These curves, which may be called curves of specific fuel consumption—above all—indicate the necessary variation in carburetor compensation and spark adjustment with throttle position if maximum

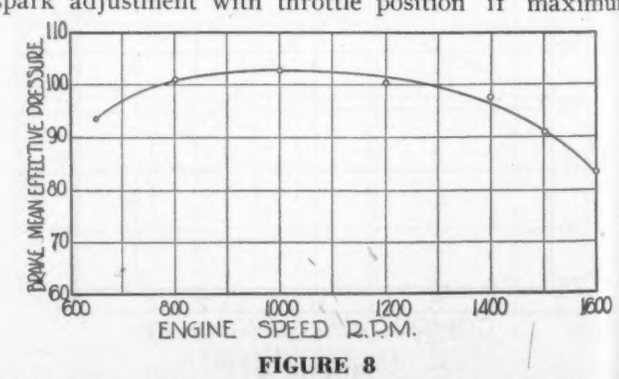

FIGURE 8

The Effect of Engine Speed on Output when Operating at Constant Compression Ratio, with Mixture Ratio and Spark Setting for Maximum Power.

economy is desired over the entire range of operating speeds. The critical nature of the economy curve for small throttle settings may be noted in Figure 9. At butane-air mixtures of 15.0 to 1, by weight, the economy was 1.88 pounds fuel per hour per brake horsepower (B.H.P.); while at a butane-air mixture ratio of 16.5 to 1, the economy was 6.25 pounds fuel per hour per B.H.P. A similar variation will be noted at throttle position corresponding to an air intake of 17.5 pounds of air per hour. This curve indicates without doubt that the leanest mixture possible for good running conditions will not necessarily yield the highest economy, and that carburetors compensated to give constant mixture ratios under all conditions of operation do not yield the best economy of the engine. A similar relation is indicated in Figure 10 for the variation in spark setting.

The dashed curves in Figure 9 and 10 are cross-plots for the variation of maximum B.M.E.P. as a function of butane-air mixtures and spark settings. These variations are similar to those for maximum economy. The variations in maximum B.M.E.P. as a function of butane-air mixtures are not as great with throttle variations as the economy; hence can be more easily compensated. The variation in spark position for maximum B.M.E.P. is over the same range as for maximum economy and may, therefore, be easily controlled by mechanisms energized by the intake manifold depression.

Sufficient tests have not been made to draw any definite conclusions at this time on the effect of the various

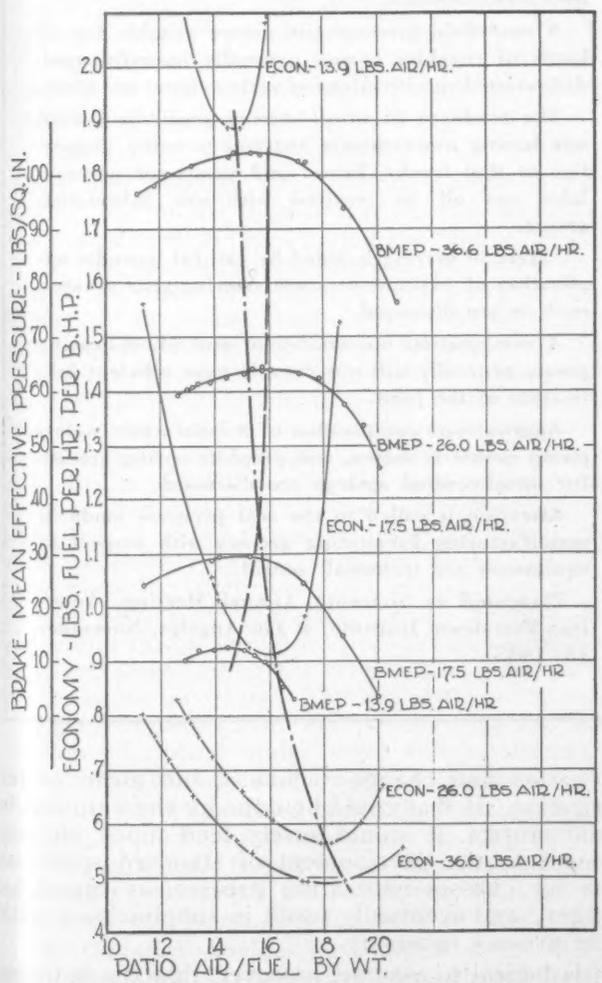

FIGURE 9

The Effect of Mixture Ratio and Throttle Position on the Economy and Power when Operating with Butane-Air Mixtures at 1,000 R.P.M. and Compression Ratio of 6.08.

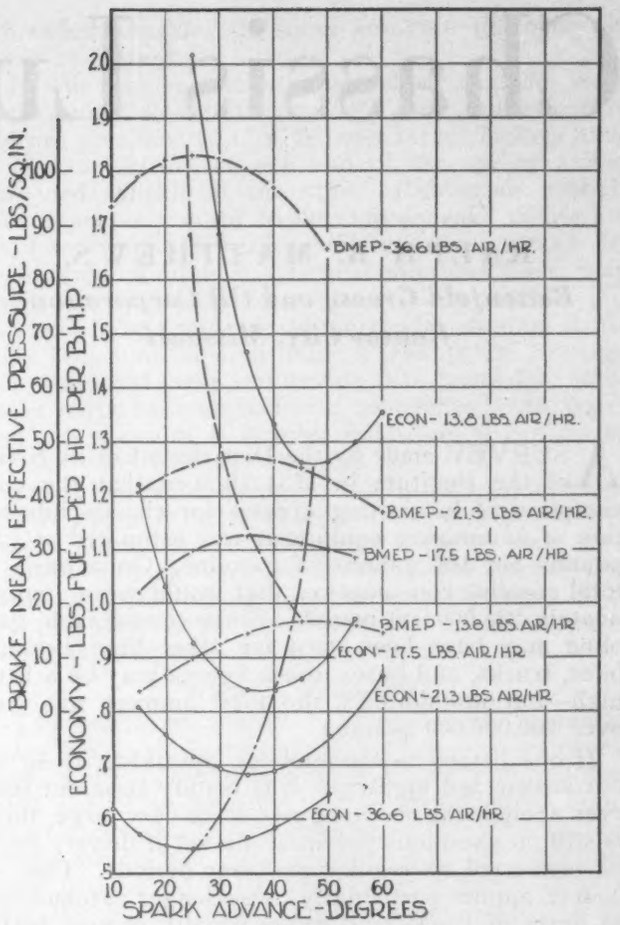

FIGURE 10

The Effect of Spark Setting and Throttle Position on Economy and Power when Operating with Butane-Air Mixtures at 1,000 R.P.M. and Compression Ratio of 6.08.

fuels and conditions of operation on the oil in the crankcase. Indications are that with gaseous fuels the sludge content of the crankcase oil is minimized, and that lighter oil may be used due to the lack of dilution.

SUMMARY

The results of these investigations have indicated the importance of close observations and control of the many variables encountered in tests on internal-combustion engines if these variables are to be separated.

In comparison with previous data[9] butane-air mixtures for internal-combustion engines are in most respects more easily controlled in multi-cylinder engines than are gasoline-air mixtures, and under optimum operating conditions show better performance.

ACKNOWLEDGMENT

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Chassis Lubricating Greases

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EVEN though chassis lubricating greases manufactured in 1934 reached a quantity of over 200,000,000 pounds, it should have been larger if all automobiles had been greased at proper intervals with the correct lubricating greases. Stressing the increased factor of safety in driving well-lubricated cars would be a public service, and would also increase consumption of lubricating greases.

Attention is called to changes of chassis equipment which have influenced and are influencing the type and grade of chassis lubricating greases now manufactured.

A semi-fluid pressure-gun grease suitable for all kinds of shackles is now generally manufactured. Abbreviated specifications of various types are given.

The tendency in wheel-bearing grease is toward one having non-corrosive extreme-pressure properties so that trucks, buses, and passenger automobiles can all be serviced with one lubricating grease.

Safety in driving is aided by careful periodic application of extreme-pressure steering-gear greases, such as are discussed.

A combination universal-joint and wheel-bearing grease generally will not provide most efficient lubrication of the joint.

Approximate composition of a satisfactory water-pump grease is shown, and graphite spring greases for metal-covered springs are discussed.

Attention is called to the real progress made in manufacturing lubricating greases with respect to equipment and technical control.

Presented at Sixteenth Annual Meeting, American Petroleum Institute, at Los Angeles, November 13, 1935.

A SURVEY made by the Department of Statistics of the Institute in 1934 showed that the consumption of lubricating greases for chassis lubrication of automotive equipment was estimated at 1.56 pounds per 100 gallons of gasoline. On a basis of total gasoline consumption, that would mean approximately 285,000,000 pounds. Since considerable gasoline may have been used for other than automobiles, trucks, and buses, these figures may be a little high—but undoubtedly the total amount was well over 200,000,000 pounds.

If one listens to automobiles squeaking along on our streets and highways, it is readily apparent that, even though the above figures seem very large, there is still an enormous potential market if drivers could be converted to regular greasing periods. This, of course, applies particularly to passenger automobiles, as fleets of trucks and buses usually receive better attention.

When the gasoline supply of an automobile is exhausted, the engine stops and gasoline must be purchased if further progress is desired. However, that same car can squeak, squeak, squeak for mile after mile, practically crying for grease—and there is no response from the driver. How much pleasanter and safer it would be for such people if their automobiles could balk and refuse to move until thoroughly greased.

It seems that the gospel of specialized lubrication, requiring the application of proper and specific lubricating greases to the automobile chassis, has been so widespread that all greasing is now done that way. Actual field contacts, however, are a sad revelation that many are still stocking only two or three products and do not have the proper equipment for first-class work. Thus the motorist who wants an efficient grease job should still first investigate as to equipment and lubricating greases available.

Progress is being made, however, in converting all concerned to the correct application of the various needed lubricants at the proper time intervals. The large and some small oil companies have been active. The manufacturers of lubricating greases have passed out a world of information to their trade.

Churchill[1] last year called attention to changes in design which would make chassis lubrication easier. However, manufacturers evidently feel that style must come first; so now we have skirts and changes in body design which really make correct greasing more difficult.

Blackwood and Spencer,[2] in their excellent paper on chassis lubrication problems, clearly show the need for standardization of chassis parts requiring lubrication and changes which would mean better lubrication. If that could be done by the automobile manufacturers, it would surely lend much encouragement to the development of standard specifications for chassis lubricating greases, as urged by Mougey,[3] and eventually result in simplification with fewer greases necessary.

It is logical to assume, however, that the automobile manufacturers are in the same position as the manufacturers of lubricating greases, in that differences have sales value of more or less importance. With the automobile, however, a careful analysis

might show that other features could be stressed with as good or better results.

SAFETY SHOULD BE STRESSED

A very laudable campaign is now being made to reduce automobile accidents. The loss of life and those maimed forever are bad enough, but there is also a terrific economic loss due to lost time and destroyed property.

While in general it is true the driver is responsible for the accident, the condition of the automobile also has a bearing. If it has not been greased for months, difficult handling or slow response may cause a wreck.

Frequently we read of accidents caused by broken steering gears. No doubt wheel bearings, universal-joint failures, or gear trouble may sometimes be responsible—even though something else is blamed.

Those charged with lubrication of automobiles have a grave responsibility. They should see that the correct lubricating greases are properly applied at the stated intervals. They should also urge, and keep on urging, all automobile drivers to have their cars greased regularly. It is an extra insurance against accident which has a small annual cost.

CHASSIS EQUIPMENT

Before discussing chassis lubricating greases, it might be well first to consider briefly the equipment on which they are used, as that has influenced the type and consistency of the greases. Since the largest quantity of lubricating grease is consumed on shackles and related bearing, shackles and bearings are placed first.

SHACKLES

The old so-called straight-bolt shackle is slowly passing out of the picture due to the development of more efficient types. Among the first of these was the Tryon shackle, which embodies reservoirs of lubricant, and was an effort to get away from the "freezing" of shackle bolts which had been prevalent—especially where greasing was neglected. There is also an excellent arrangement for keeping the shackle tight. Unfortunately, the manufacturers of that shackle and the automobile manufacturers did not specify the best lubricant or give sufficient publicity to the effect that a special type was necessary. First a transmission oil was recommended; and when it was found to empty from the grease reservoirs too quickly, felts were placed at the ends of the reservoirs—but they were not entirely satisfactory. In the meantime lubricating-grease manufacturers had found that a semi-fluid pressure-gun grease was best, and were calling the attention of their trade to the necessity for its use. The application of pressure-gun greases not of semi-fluid consistency and transmission oil caused undue wear which required the replacement of thousands of Tryon shackles.

About the same time the roller-bearing type of shackle, requiring lubrication only at long intervals, was brought out. It seemed to be satisfactory; but apparently was found too expensive, as it was discontinued except on higher-priced models.

The threaded shackles next appeared, the first being a threaded bolt with the conventional hole for the grease going to the center so it could spread each way on the threads. Later came the so-called "U" type, with threads on both arms of the "U," and the grease applied at the ends of the sleeves. Threaded shackles of some sort are decidedly in favor at present.

It will also be recalled that rubber shackles were earlier used all around on some cars; but evidently did not give best results, as most recent models have a rubber shackle at one end of the spring and a threaded shackle at the other. Rubber or rubberized shackles are apt to develop squeaks which are hard to eliminate, because oil or grease causes deterioration of rubber. Glycerin mixtures have been used, but do not last long.

There have not been any particular changes in tie rods, king pins, or drag links. Probably the bearings are somewhat more serviceable than formerly. Since these parts have an intimate connection with poper and safe steering, it is most important that they be efficiently lubricated at all times.

Individual front springing has introduced bearings which add a little to the quantity of pressure-gun grease needed for chassis lubrication of such cars. Those servicing such equipment have found that greasing more frequently is necessary if wear is to be prevented. Even where the most durable type of grease is used, such has proved to be the case.

WHEEL BEARINGS

The increased use of roller bearings in recent years has made better wheel-bearing greases necessary, as it was found that roller bearings were somewhat harder to lubricate than ball bearings. Four-wheel brakes made it obligatory to use a lubricating grease which had good resistance to the softening effect of heat, so the grease would not leak or flow onto the brake bands. The bearing manufacturers are giving much attention to lubrication and, acting in unison, are doing work on a machine which will provide accelerated tests of wheel-bearing greases. If practical, such apparatus should be helpful in assuring better wheel-bearing lubrication.

STEERING GEARS

Improvements have been made in both cam-and-lever and worm types of steering gears. Particular attention has been given to ease of operation, rugged construction, and safety. One manufacturer of the former type has developed a rotating cam which has proved to be a signal improvement. At times high pressures are produced on bearing surfaces of steering gears and, consequently, extreme-pressure greases are finding favor for most efficient lubrication.

UNIVERSAL JOINTS

The introduction and present use of roller or so-called needle-type universal joints means a decided change in lubrication requirements. The old-style grease-lubricated joint and that serviced with oil will slowly pass out of the picture, and the demand for such grease will eventually be relatively small. Mileage intervals recommended for lubrication of the needle-bearing universal joints are long, and in some cases for life of the car. The latter, however, will not generally be endorsed by those wishing best lubrication. Splines must be greased regularly, but the right type of pressure-gun grease is satisfactory. As all power from the engine must pass through the universal joint or joints, it is highly important that they be effectively lubricated.

WATER PUMPS

Some grease-lubricated water pumps are now being made so the bearings are not in contact with the

circulating liquid. That is a good improvement, because it minimizes the danger of grease being carried to and deposited onto cooling surfaces with resulting loss of cooling efficiency. Even for such pumps, the water-pump grease should be high enough in dropping or melting point to resist the softening effect of the hot circulating liquid. Some are using an oil-lubricated water pump; but if the owner is neglectful, wear may result sooner than with grease-lubricated water pumps.

THE LUBRICATING GREASES FOR THE CHASSIS

PRESSURE-GUN GREASE

Even though the cars equipped with straight-bolt shackles and also Tryon shackles will eventually no longer be in service, there are now many being driven every day. Consequently, those offering efficient lubrication service must have pressure-gun greases particularly suitable to individual types of shackles or, obviously better, one which will effectively care for all kinds, as stocks are thereby reduced and less greasing equipment required.

As previously mentioned, the use of the Tryon shackle led to the manufacture of semi-fluid pressure-gun greases which, as the name indicates, have more fluidity than those previously in use. It was also found that, if a lubricating oil of higher viscosity was used, the durability of the grease was increased. Further, such a product proved very satisfactory for straight-bolt shackles and all types of threaded-bolt shackles. Thus it answered the need for a product suitable for all shackles.

One of the desirable attributes of a lubricating grease for Tryon and also threaded shackles is the property of feeding slowly and steadily from the grease reservoirs to the bearing surfaces. It has seemed that a little tackiness is helpful in that direction, and also assists the grease in clinging to the bearing surface. There should not be so much, however, as to cause the grease to string away at length from the fitting after the gun has been disconnected. Reference to grease reservoirs of the threaded shackles is made because the ends of the sleeves of "U" shackles hold some grease which can feed to the threads, and the same action occurs to a limited degree from the grease passages of other threaded shackles.

In view of their utility, semi-fluid pressure-gun greases or chassis lubricants, as some prefer to call them, have naturally grown in favor. Calcium, sodium, and aluminum bases are all being used in their manufacture. Probably some of mixed base are also offered to the trade.

Since A. J. Stevens, in about 1925, perfected a method for the manufacture of aluminum-base lubricating greases of uniformity and good keeping quality, they have gained in popularity. The solubility of the base in oil eliminates the necessity of any "tie water," and with the proper oil gives a lubricating grease of such clarity and attractive appearance that its purity cannot be questioned. That has proved a decided sales asset.

The presence of only a trace of moisture allows this product, as a whole, to serve as a lubricant, and thus increases its effectiveness. No deterioration and no hardening with age are valuable properties from the standpoint of storage and elimination of clogged fittings which are possible with other types of lubricating greases, particularly if regular greasing is neglected.

Because of the above, and because of excellent service results, the volume of aluminum-base semi-fluid pressure-gun greases manufactured has increased each year. In addition to use as a chassis lubricant, they give fine results in lubricating speedometer and cables, oil-type universal joints, oscillating mechanism of windshield wipers, the springs, and other points where squeaks develop.

Klemgard,[4] with his special laboratory service-testing apparatus, using straight-bolt and threaded shackles, has shown that aluminum-base pressure-gun greases have as good resistance to emulsion with water as calcium-base greases. That conclusion is amply supported by road service. Grease-retention tests showed a comparatively high loss at first, after which the curve flattened—with plenty of grease remaining for satisfactory lubrication. The approximate composition of semi-fluid pressure-gun greases is shown in Table 1.

In view of the federal excise tax on lubricating greases with a worked penetration of over 390, the summer grades of most semi-fluid pressure-gun greases are kept below that figure.

Most consumers have found a winter grade necessary in sections experiencing cold winter weather. It is manufactured in a lighter consistency, and generally contains an oil somewhat lower in viscosity. That grade is necessary not only from the standpoint of application—especially where closed greasing facilities are not available—but also so that the lubricating grease will not be too stiff to function properly at low temperatures.

Extreme-pressure lubricating greases for this purpose have been advocated by some; but it has been largely for sales reasons, as only heavily-loaded trucks might possibly profit by their use.

Of course, large quantities of soft cup greases and gun greases containing low-viscosity oils—also probably transmission oil—are still used for chassis lubrication. Those applying such products purchase on price only, and overlook the fact—or do not care—that their unsuitability and lack of durability cause excessive wear.

WHEEL-BEARING GREASE

In general, automobile manufacturers, with the support of the companies making bearings, are recommending a short-fiber soda-base grease containing

TABLE 1
Approximate Composition of Semi-Fluid Pressure-Gun Greases

	Soap Content (Maximum)	Water (Maximum) (Percent)	ASTM Worked Penetration	Texture	Saybolt Viscosity of Oil Content (Minimum)	Color of Oil
Aluminum base	11 percent aluminum	Trace	340–380	Tacky	150 at 210° F.	Black
Aluminum base	9 percent aluminum	Trace	340–370	Tacky	110 at 210° F.	5–6 ASTM
Calcium base	8 percent calcium	1	340–380	Smooth	95 at 210° F.	Black
Calcium base	6 percent calcium	1	350–400	Smooth	140 at 210° F.	8 ASTM (maximum)
Sodium base	5 percent sodium	0.25	360–390	Tacky	175 at 210° F.	Green

TABLE 2
Specifications of Typical Wheel-Bearing Greases

	Soap Content (Maximum—Percent)	Water (Maximum—Percent)	ASTM Worked Penetration	Dropping Point (Minimum ° F.)	Texture	Saybolt Viscosity of Oil Content (Minimum)
Calcium base.....	18	1	185–215	200	Smooth	480 at 100° F.
Sodium base.....	13	0.5	280–310	325	Fibrous	130 at 210° F.
Mixed base*.....	18	0.5	250–390	290	Fibrous	120 at 210° F.

* Not more than 3 percent of calcium base; balance sodium base.
Non-corrosive EP base can be added in proper proportion to any of the above greases if an EP wheel-bearing grease is desired.

an oil of not less than 300 Saybolt viscosity at 100° F. for lubrication of wheel bearings.

The relatively high softening point of such a product no doubt is the primary reason for its choice—this to minimize the tendency of the grease to get over onto the brake bands.

Klemgard[4] found in his laboratory service tests that calcium-base wheel-bearing greases leaked badly in comparison with sodium-base products, with consequent development of higher temperatures. The fact remains, however, that thousands of pounds of the former have been used with satisfactory results on passenger automobiles. The instruction book of one automobile company still recommends a No. 2½ cup grease. No doubt correct application of limited quantities of a calcium-base wheel-bearing grease has a distinct bearing on the service obtained.

From the standpoint of safety, and also lubrication, the ideal combination for a wheel-bearing grease would embody good resistance to softening by heat, also a smooth texture and consistency—causing it to follow closely the bearings with a complete cushioning effect. Greatest durability would probably be obtained where the worked and unworked penetrations are fairly close together. The lubricating oil in the grease should not be below the minimum viscosity noted above, and not so high as to interfere with the grease functioning as suggested. In order to approach these desired characteristics, some manufacturers are marketing a mixed-base wheel-bearing grease containing both calcium- and sodium-base greases.

Typical wheel-bearing greases on the market are covered by the abbreviated specifications in Table 2.

While pressures developed on wheel bearings of passenger automobiles are ordinarily not high, there is a growing sentiment for the use of EP wheel-bearing grease. Maag[5] has pointed out the advantages of that type for lubrication of bearings in industrial use and predicts: "Most greases of tomorrow will undoubtedly be of the extreme-pressure type."

At least one automobile company is experimenting with EP wheel-bearing grease, and has found it helpful in protecting the bearings during the break-in period. No doubt for trucks in heavy-duty service such a wheel-bearing grease would be more effective; so it might be best to give extreme-pressure properties to all wheel-bearing greases, and thus avoid the necessity of stocking another grade. "Mild" EP properties should be satisfactory, and thus the lubricants would only need to pass 24-26 pounds when tested on the Almen machine.

The work of Farrington and Davis in studying microscopically the length of fiber[6] will be helpful in classification of this type of lubricating grease, since heretofore it has not been possible to answer the question: "What is a short-fiber grease?" Most manufacturers have had to depend on the finger test of skilled grease makers.

STEERING-GEAR GREASE

Many rendering lubrication service do not carry a special steering-gear grease. They apply gear lubricant of either the fluid or fibrous type. While a lubricating grease manufactured specifically for that purpose gives best service, gear lubricant is fairly satisfactory—provided the housings are tight enough to hold the fluid type, and if it has extreme-pressure properties.

Resistance to channeling at low temperatures must necessarily be taken into consideration in sections having cold winters. This is very important either when a gear lubricant is used or a steering-gear grease, since it has a direct bearing on the ease of operation and response in driving.

As previously pointed out, the steering gear and connections should have careful and regular lubrication. Failure in any way at a critical time may easily result in a dangerous accident.

Since the demand for steering-gear grease is limited, the quantity manufactured is relatively small. General Motors Specifications 4567-M, covering an EP steering-gear grease containing 5 to 6 percent of calcium soap, is representative of that type; 4641-M is also a special steering-gear grease, but contains no grease base. It is required to stand a load of 24 pounds, minimum, on the Almen machine. As an aid to all-year use, the Saybolt viscosities of oils used in both products is specified at 0 as well as at other temperatures. A mixed-base EP steering-gear grease suitable for all seasons except winter will need 6 percent of calcium base and 2 percent of sodium base with an oil of Saybolt viscosity of 190-

TABLE 3
Specifications of Special Type Sodium-Base Grease

Soap Content (Maximum—Percent)	Water (Maximum—Percent)	ASTM Worked Penetration	Dropping Point (Minimum—° F.)	Texture	Saybolt Viscosity of Oil Content (Minimum)
16	0.5	315–345	320	Extremely tacky	85 at 210° F.
The following covers a combination product referred to above:					
18*	1	235–265	280	Tacky	125 at 210° F.

* 12 percent calcium soap, and balance sodium.

TABLE 4
Characteristics of a Serviceable Water-Pump Grease

Calcium Soap Base (Maximum—Percent)	Water (Maximum—Percent)	ASTM Worked Penetration	Dropping Point (Minimum ° F.)	Saybolt Viscosity of Oil Content (Min.)	Color of Oil
24	1	160–190	210	100 at 100° F.	3 ASTM

200 at 210° F., and a worked ASTM penetration of 300-330—EP compound to be added to give the above load-carrying capacity on the Almen machine.

Of course, many still give the steering gear a "shot" of pressure-gun grease; but even if a semi-fluid type is used, best lubrication will not be obtained. This will be especially true because of the average long interval before the car is again greased.

UNIVERSAL-JOINT GREASE

It can hardly be said that grease-lubricated universal joints have been, as a whole, efficiently lubricated. That is true; because some guns used do not develop enough pressure to handle a universal-joint grease of the proper consistency, or the individual applying it is so lazy that a product is wanted which will allow easy operation of the gun.

At the average road speed of today, a tremendous centrifugal force is developed at the universal joint or joints. This means that the lubricating grease must be very high both in cohesion and adhesion. In other words, it must cling closely to the bearing surfaces and at the same time resist being torn apart.

Softer universal-joint grease, which has been demanded by some for reasons stated above, is apt to be thrown—or rather pulled—from the joint by that centrifugal force, with resulting wear. Of course, neglect can also be a contributing factor.

In order to keep down stocks, some companies have used a combination universal-joint and wheel-bearing grease with reasonable success. However, such a product necessarily does not have the extreme stringiness or tackiness needed for the best universal-joint grease.

A special type of sodium-base grease, having a very long fiber, is manufactured for universal-joint grease, and approximate specifications of the finished grease are given in Table 3.

Road-service tests are the best criterion by which to judge serviceability of universal-joint greases.

WATER-PUMP GREASE

Since resistance to emulsion with water is one of the main requisites of this lubricating grease, it is customary to use a calcium base in manufacturing it.

A hard consistency is advisable, as that is an aid in resisting softening by the hot circulating liquid which passes through the pump. However, the grease should not be too hard, since in the case of cup feed it may not pass to the bearings as rapidly as it should.

The characteristics of a serviceable water-pump grease are given in Table 4.

MISCELLANEOUS LUBRICATING GREASES

Several automobile manufacturers are still recommending a cup grease for use on the distributor. Until all go to the use of a short-fiber grease, such as wheel-bearing grease, it is thus necessary for those greasing all makes of cars to carry a No. 3 cup grease. It should be the regular calcium-base product, and particularly for this purpose it is not necessary in manufacturing the grease to use an oil higher in Saybolt viscosity than 75-100 at 100° F.

The growing use of metal-covered springs is making necessary the stocking of a graphite spring grease when complete lubrication service is offered. It should have a worked penetration of 270 to 290 ASTM. The graphite spring grease that is apparently most efficient should contain 40 to 45 percent of graphite, but others are being made which contain a much smaller quantity. Some specifications call for amorphous, and others for flake graphite—which must all pass through a 200-mesh sieve.

PROGRESS HAS BEEN MADE, AND WILL CONTINUE

Lubricating-grease manufacturing is far different now from what it was in the early days, when the grease was made in a direct-fired kettle and stirred by hand with a paddle. Now modern kettles, of open and pressure types—with efficient mechanical mixers and temperature control—are in use.

The grease maker no longer uses the finger test to determine the consistency, but depends on the chemist, who checks it by a standard method on an approved apparatus. The latter has previously analyzed the various materials as insurance of uniformity.

Grease filters are necessary equipment to be sure that only absolutely clean grease is shipped to customers. Can-filling machines not only speed up that operation, but each can is cleanly filled with the exact amount of lubricating grease. Steel drums of various sizes, lithographed if desired, have practically replaced wooden barrels and kegs.

Grease chemists have already done excellent research, which has resulted in the production of better lubricating greases than have ever been available before. That work will be continued, so that eventually we shall have the needed fundamental knowledge to come closer to answering the question: "What is lubricating grease?"

More standard methods are needed for laboratory control of lubricating greases, both by manufacturers and consumers. Sub-committee IV of ASTM Committee D-2 is actively engaged in that work. Present cooperative study and experiment are largely on methods for softening points of lubricating greases under heat and consistency of very soft products.

The National Association of Lubricating Grease Manufacturers is already functioning in a way that will be an immeasurable help in future progress.

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Plates and Welds that resist LOW-TEMPERATURE EMBRITTLEMENT

• Pressure vessels used in the propane dewaxing process must be constructed of materials which will resist shock at relatively high pressure, and at temperatures as low as −50° to −75° F. At these low temperatures, most steels become brittle and liable to failure.

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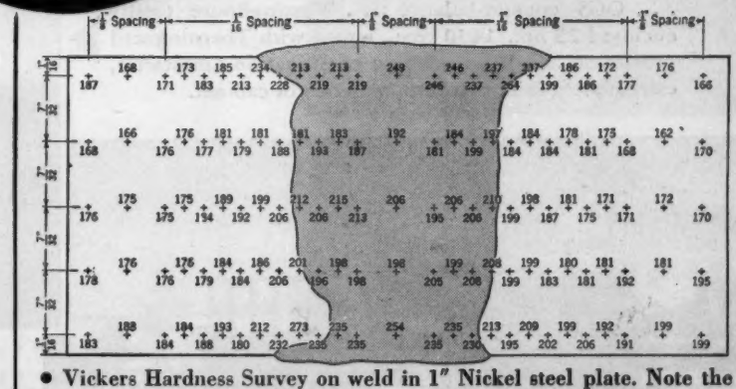
Charpy Impact in Ft. Lbs. of .25% Carbon, 2.25% Nickel Steel

Specimen Taken From	*Temperature of Test Specimen in Degrees F.*			
	+70	*0*	*−50*	*−75*
Steel Plate before Welding	32	23	20	16
Heat-Affected Zone . . .	43	..	28	..
Fusion Zone	29	..	24	..
All-Weld Metal	31	..	21	..



• Vickers Hardness Survey on weld in 1" Nickel steel plate. Note the uniformity in hardness throughout, and absence of excessive hardening at the "heat-affected zones" near the junction of the plate and the weld. Both plate and deposit contain 2 to 2½% Nickel.

• *Below*—Pressure vessel of 2½% Nickel steel, enroute to Union Oil Co. from A. O. Smith Corp., Milwaukee, Wisconsin.

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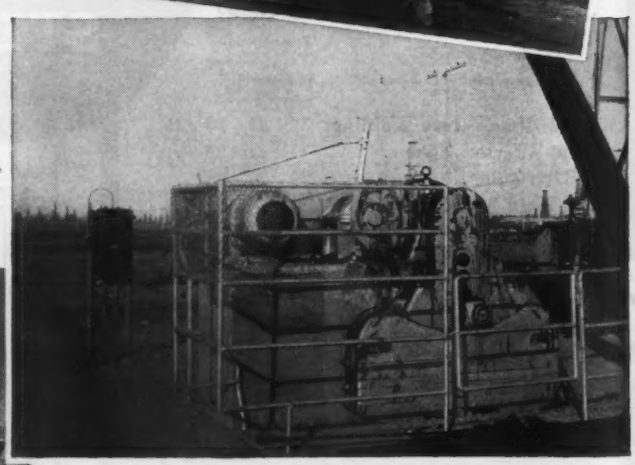

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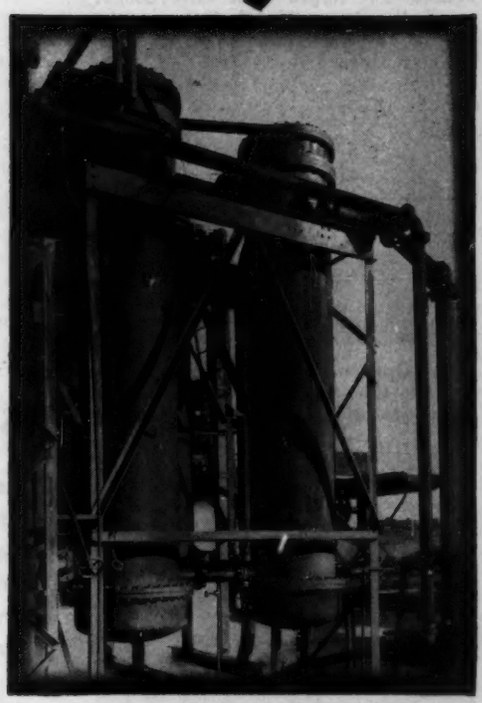

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Heat Exchangers
Instruments
Lighting Equipment
Meters
Micarta Products
Motors and Control
Nofuze Circuit Breakers
Switches
Transformers
Turbines

Westinghouse

Here's a KEROTEST about to be inspected under full 2000 pounds cylinder pressure without interrupting the welder. First, he turns the valve stem left to the full open position.

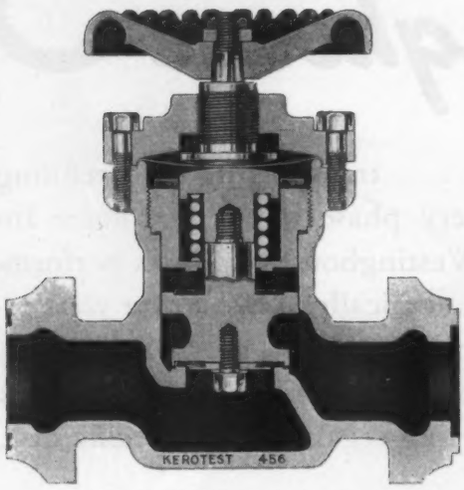
Second—The forged brass valve bonnet cap is then tapped lightly to loosen the threads.

Third—Open end wrench is applied to the two flat sides of the bonnet cap and unscrewed by turning to the left.

Fourth—KEROTEST Diaphragm Discs are lifted out of valve for inspection or replacement while the welder continues his work without the slightest interruption—an exclusive KEROTEST feature.

Fifth—After discs are replaced, the bonnet cap is set back on the valve and screwed tight.

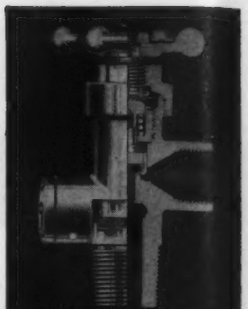
There's a KEROTEST DIAPHRAGM PACKLESS VALVE *and* FITTING *for* EVERY PROPANE GAS INSTALLATION



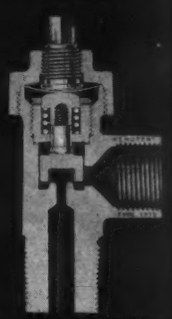
Sectional view of the new Kerotest Type 456 Diaphragm Packless Globe Valve with 4 bolt hole square type flanges.

PRESSURE-SAFE CONVENIENT ECONOMICAL

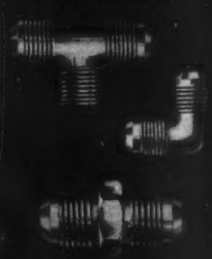
Kerotests are the ideal valves for modern propane gas service—the only valves that can be repaired while under full pressure and without interrupting service from the line. They are now available in the larger sizes up to 1½". Also available is a complete line of flare crosses, tees, elbows, unions, nuts and manifolds, built to the same high standard of Kerotest quality.



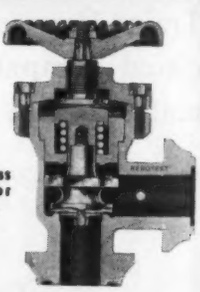
New Diaphragm Packless Valve with spring safety device for propane gas cylinders.



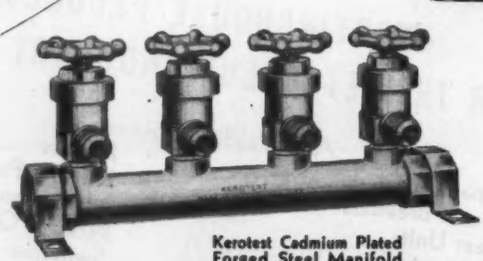
Diaphragm Packless Valve without safety device for Propane cylinders.



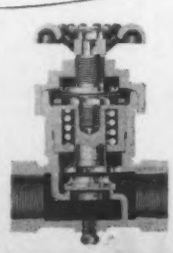
Kerotest quality tees, elbows, unions, nuts—available in all standard sizes.



Diaphragm Packless Angle Valve for Propane Gas lines.



Kerotest Cadmium Plated Forged Steel Manifold equipped with Diaphragm Packless Valves suitable for the largest installations.



Diaphragm Packless Globe Valve.

KEROTEST

KEROTEST MANUFACTURING CO.

PITTSBURGH, PA.

The Look Box

(*Continued from page 496*)

Dubbs Process Patents Upheld by Supreme Court

COMPLETE victory for Universal Oil Products Company and the Dubbs proces marks the end of the celebrated patent infringement suit, Universal Oil Products Company vs. Root Refining Company.

On October 21, the Supreme Court of the United States, by denying the petition of defendant for writs of certiorari, wrote the last chapter in the case and closed the book except for the accounting to determine the amount due the plaintiff.

By that action, the court of last resort refused to disturb the findings of a United States district court, upheld unanimously by the three judges of the Circuit Court of Appeals of the Third Circuit, that the two patents (Dubbs and Egloff) involved in the suit, are valid patents and that Root Refining Company infringed them by operation of a so-called Winkler-Koch cracking unit.

A decree will be entered in accordance with the opinion of the lower courts, an injunction will issue against the defendant restraining further infringement, and the case will be referred to a master for an accounting of profits and for the assessment of damages.

The final decision is held to be one of the most important ever handed down in oil-industry litigation, because a clean-cut issue was drawn between the owner of the Dubbs cracking process, invented, developed and improved under patent protection and operated under license agreement, and the operator of an unpatented and unlicensed cracking unit, who claimed, first, that the Dubbs and Egloff patents were invalid, and, second, that his cracking unit did not infringe them.

The two patents involved are No. 1,392,629, issued to C. P. Dubbs, October 4, 1921, generally referred to as the clean circulation patent, and No. 1,537,593, issued to Gustav Egloff, May 25, 1925, known as the multiple coil or selective cracking patent. Both are owned by Universal Oil Products Company.

Root Refining Company, whose refinery is at El Dorado, Arkansas, was formerly a licensee of Universal Oil Products Company, having two Dubbs cracking units, which were installed in 1925 and 1926 respectively. Winkler-Koch Engineering Company later installed in the Root plant a 3000-barrel cracking unit operation of which the courts in this case have found to infringe the Dubbs and Egloff patents.

Hearing of the suit was begun June 21, 1932, before Judge John P. Nields in the United States District Court of Wilmington, Delaware. Judge Nields handed down his decision in the case April 27, 1934. He held that the two Universal patents in suit are valid and that they were infringed by the operation of the so-called Winkler-Koch cracking unit by the Root company.

Defendant appealed the case to the United States Circuit Court of Appeals of the Third District, sitting in Philadelphia, and on June 26, 1935, this three-judge court handed down a unanimous opinion in favor of Universal Oil Products Company.

A petition for rehearing, filed by the defendant, was denied by the Circuit Court of Appeals, August 5, 1935, and the appeal to the United States Supreme Court for writs of certiorari followed. It is this petition that has just been denied.

It is understood that Universal Oil Products Company is diligently prosecuting legal action against other infringing refiners in various parts of the country.

Bureau of Mines Analyzes Rodessa, Louisiana Crude

CRUDE oil produced from the discovery well in the new oil field at Rodessa, Caddo Parish, Louisiana, is paraffiin base, according to the method of classifying crude petroleum with respect to base, devised by the United States Bureau of Mines. The bureau's laboratory analysis of a sample of oil from I. L. Young 1 indicates that the crude contains approximately 32 percent of gasoline and naphtha, 20 percent of kerosene distillate and 25 percent of gas oil and heavier distillates suitable for use as fuel oil or for cracking.

Natural gas has been produced in the Rodessa field for a number of years. The oil-producing formation in the field is found approximately 6000 feet below the surface in what is reported by geologists to be the Upper Trinity (Glen Rose lime). The Rodesso gas field is at the junction of the boundaries of Louisiana, Arkansas, and Texas. Present belief regarding structural conditions has resulted in prospecting into Texas and Arkansas.

If the oil-producing portion of the field should be found to extend into these adjoining states, a major problem of cooperative regulation pertaining to development, including well spacing, and proration of production may be presented, for this would be the first instance of a single producing reservoir in which three states are involved.

Bureau of Mines Analyzes Oxford, Kansas, Crude Oil

THE oil produced from the newly-discovered lower horizon in the Oxford field, Sumner County, Kansas, is a high grade wax-bearing intermediate base oil, according to the method of classifying crude petroleum with respect to base, formulated by the United States Bureau of Mines. The bureau recently has made a laboratory analysis of a sample from Gassoway 1A well, completed by Amerada Petroleum Corporation and Sunray Oil Company on September 12, 1935. The analysis indicates that the oil contains approximately 32 percent of gasoline and naphtha, 12 percent of kerosene distillate, and 12 percent of light gas oil suitable for use as fuel or for cracking. Heavier distillates may be suitable for manufacture of lubricants, or they may be better adapted for cracking or for use as fuel. The sulphur content of the crude oil is low.

Annual Meeting of C.N.G.A Held Nov. 11

THE California Natural Gasoline Association held its fall annual meeting November 11, the first day of the American Petroleum Institute convention at the Biltmore Hotel, Los Angeles. Morning and afternoon business sessions were held to which A.P.I. visitors were invited. A feature of the association meeting was an address by Dr. Gustav Egloff, Universal Oil Products Company, dealing with the subject of polymerization. The following program was presented:

Address of welcome by President T. L. Taggart, "Making high octane gasolines out of propanes and butanes" by Dr. Gustav Egloff.

"Rectifying Straight-Run Gasoline to Improve Its Qualities by Removing Isobutane and Lighter Fractions and Using More Natural Gasoline," by Dr. G. G. Brown, University of Michigan.

"Standards for Application of Super-Compressibility Factors in High Pressure Natural Gas Measurement," was the subject discussed by W. E. Helmick.

R. R. Crippen, The Texas Company, discussed " C.N.G.A. Reid Vapor Pressure Testing Procedure."

C. D. Gard and H. J. Multer in their discussion of charcoal gasoline content procedures, discussed "General Problems, Including Sampling Procedure," and "Distillation Procedure."

Grease Makers Hold Third Meeting

THE third annual convention of the National Association of Lubricating Grease Manufacturers was held in Chicago, October 14 and 15 at the Stevens Hotel. Among the speakers on the interesting and timely program were: H. A. MacConville, General Electric Company, who discussed "Practical Tests for Industrial Greases"; C. R. Ahlberg, Standard Steel Bearing Company, whose subject was "Anti-Friction Bearing Lubricants"; F. E. Huggins, Jr., Sowers Manufacturing Company, spoke on "Modern Methods of Grease Manufacture"; A. R. Lange, Swann-Finch Company, discussed "Grease — Past, Present and Future"; and J. Howard Pyle, Chek-Chart, Inc., discussed "Safeguarding the Investment."

New Members A.P.I Board

RESIGNATION from the board of directors of the American Petroleum Institute of Ralph T. Zook was accepted, and the board elected the following new members:

W. H. Berg, vice president of Standard Oil Company of California, San Francisco, in the production group—term expiring in 1936—to succeed Oscar Sutro, deceased.

Torkild Rieber, vice president of The Texas Company, in the at-large group—term expiring in 1936—to succeed C. B. Ames, deceased.

T. P. Thompson, Jr., president, Pennsylvania Grade Crude Oil Association, Bradford, in the at-large group—term expiring in 1935—to succeed Ralph T. Zook, resigned.

Reserve Analysis and State Compacts Dominate A.P.I.

THROUGH the program of the Sixteenth Annual Meeting of the American Petroleum Institute, November 11, 12, 13 and 14, the petroleum industry put itself on record as capable of providing the people of the United States with sufficient petroleum products as a private industry. Federal control was frowned upon. State regulation of production with the assistance of the interstate oil compact was approved. Reserves were estimated as sufficient.

These were a few of the impressions from the subjects discussed by leaders of both the industry and officials of two of the oil producing states.

The position of the industry on the question of federal control was outlined by Axtell J. Byles, president, who stated the case of private endeavor as an incentive for finding and developing oil reserves.

The board of directors considered the report of a special committee on reserves and recommended it for printing and study.

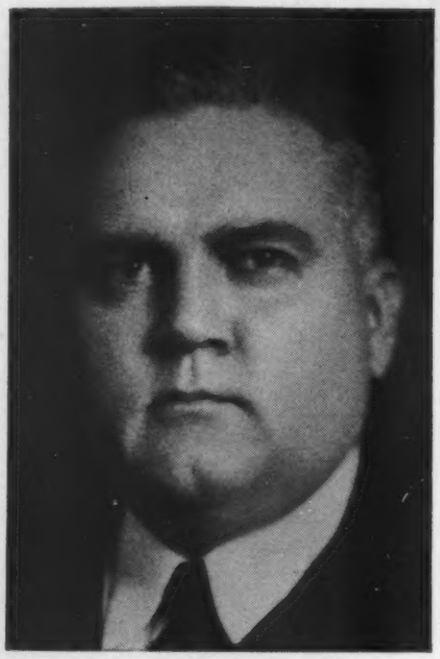
President Byles dealt with this report in his address. The substance of this was that from oil, coal and shale there are ample reserves for the nation and that the industry is equipped to develop them.

The interstate oil compact was presented by Tom Anglin of Oklahoma, who read the speech prepared by Governor E. W. Marland of that state. Governor Marland was unable to attend. He set out the possible benefits of the compact and presented it as the only constitutional method left to the states for moving as a unit in conserving oil and gas.

Colonel E. O. Thompson, chairman of the Texas Railroad Commission, branded federal control as unnecessary and expressed the opinion that there is not immediate danger of such legislation.

Chicago was selected as the scene for the Seventeenth Annual Meeting, which will be held November 9, 10, 11 and 12, 1936. The Stevens Hotel will be headquarters.

JACOB FRANCE
Elected Vice President for Refining, American Petroleum Institute



GEORGE A. HILL, JR.
Re-elected Vice President for Production, American Petroleum Institute

AXTELL J. BYLES
Re-elected President, American Petroleum Institute

New Officers

Axtell J. Byles of New York was re-elected president of the institute.

Other officers elected were: Vice President at Large, K. R. Kingsbury, Standard Oil Company of California, San Francisco, re-elected; Vice President for Production, George A. Hill, Jr., Houston Oil Company of Texas, Houston, re-elected; Vice President for Refining, Jacob France, Mid-Continent Petroleum Corporation, Baltimore, to succeed W. G. Skelly, Skelly Oil Company, Tulsa; Vice President for Marketing, C. E. Arnott, Socony-Vacuum Oil Company, New York, re-elected; Executive Vice President, W. R. Boyd, Jr., New York, re-elected; Treasurer, O. D. Donnell, Ohio Oil Company, Findlay, Ohio, to succeed D. J. Moran, Continental Oil Company, Ponca City; and Secretary and Assistant Treasurer, Lacey Walker, New York, re-elected.

The board appointed the following executive committee: F. A. Leovy, Gulf Oil Corporation, Pittsburgh; J. Howard Pew, Sun Oil Company, Philadelphia; E. G. Seubert, Standard Oil Company of Indiana, Chicago; H. F. Sinclair, Consolidated Oil Corporation, New York; W. C. Teagle, Standard Oil Company of New Jersey, New York; J. C. VanEck, Shell Union Oil Company, New York.

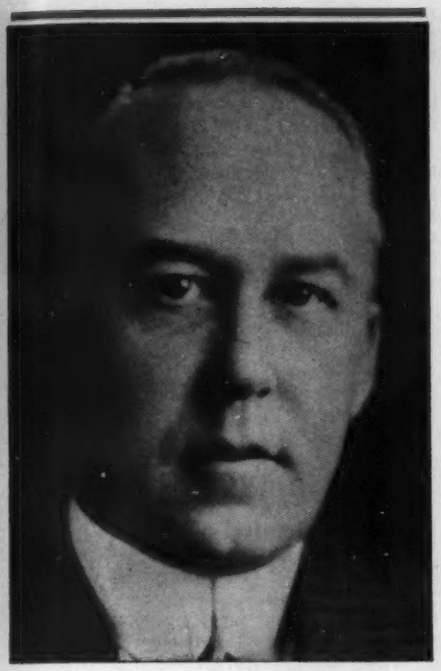
The following committee on membership was appointed: D. E. Buchanon, Hanlon-Buchanon, Incorporated, Tulsa; R. A. Bloomfield, Barnsdall Oil Company of California, Los Angeles, W. H. Ferguson, Continental Oil Company, Denver, Colorado; E. J. Bulock, Standard Oil Company of Indiana, Chicago; and Jake L. Hamon, Cox & Hamon, Dallas.

National Politics Out

Nowhere on the program did a man high in the affairs of the national administration appear. However, two men from political families of the two leading oil producing states were on the program.

The difference in the 1935 program of the Institute and the two previous years represents a picture of the change that has occurred in one of the nation's major industries. In Chicago two years ago Secretary Harold L. Ickes of the Department of Interior and administrator of the petroleum code, explained the workings of the partnership between government and industry. Last year in Dallas, Secretary Ickes came back as an institute speaker, and scolded the industry.

The program this year did not call upon any man in Washington to discuss national government proposals for the petroleum industry. Furthermore, several speakers on the institute program predicted lessened federal control agitation. Not only did the official program present the impression that the personnel of the industry is convinced the best operation will come



K. R. KINGSBURY
Re-elected Vice President at Large, American Petroleum Institute

through private endeavor, but casual conversations between friends reflected the same thought.

Crude Reserves Stressed

On two occasions during the meeting crude reserves was the principal subject discussed. It was pointed out that no national crisis caused by a shortage of petroleum products now impends, nor is likely to occur. The nation's proved petroleum reserves are not only 100 percent greater now than 10 years ago, but are adequate to meet the demand for at least 25 years if properly managed, it was declared. Moreover, there is an unlimited supply of petroleum products available from coal and oil shales when needed. These important facts were brought out in a report submitted to the board of directors of the American Petroleum Institute by its executive committee, and by the Institute's president, Axtell J. Byles, in his address. The full text of the executive committee report appears elsewhere in this issue of THE OIL WEEKLY.

It was explained that the report was presented not only to reveal the industry's present position and its future outlook, but also to refute the charges of alarmists that petroleum reserves are in danger of early exhaustion, that the industry has been wasteful and unwilling or unable to cooperate in their conservation, and that rigorous governmental control, or making the industry a public utility, is necessary. Declaring that the industry previously has been called upon to dispel fears about the available supply of petroleum, the report recalls that in 1925 a similar study was undertaken by the institute.

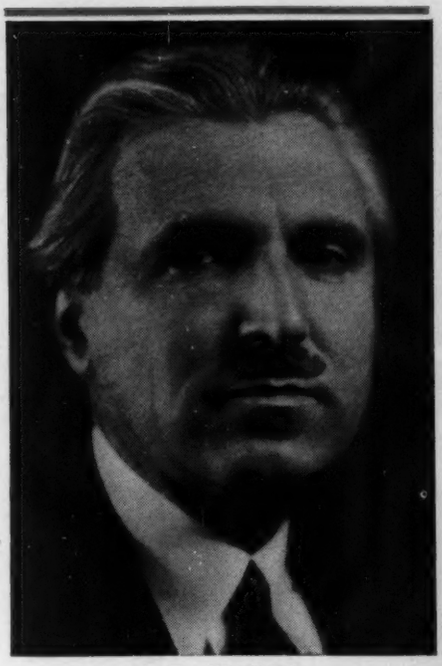
President Byles in his address stated that if left as an industry free of bureaucratic control, petroleum is capable of providing motor fuel and lubricants for the people of the United States for as long as there are natural resources capable of being converted into energy for the internal combustion engine.

Concerning reserves, Byles said:

"The current survey, which gives careful consideration to the various items affecting demand, indicates that in 1950 we will require a daily crude oil production of 3,041,000 barrels, this demand declining by 1960 to 2,926,000 barrels per day.

Insterstate Compact Boosted

The Interstate oil compact came in for favorable mention in several instances. President Byles declared that there is no power under the federal constitution for the federal government to control the production of oil which is mining, any more than the refining of oil, which is manufacturing. That power, he said, is reserved to the states.



C. E. ARNOTT
Re-elected Vice President for Marketing

In the interstate compact the petroleum industry has its opportunity to accomplish conservation, stabilization and avoid federal control. This was the basis on which the compact was presented to the oil men at the meeting by Tom Anglin, speaking for Governor E. W. Marland of Oklahoma, chairman of the interstate oil compact commission. Ernest O. Thompson, chairman of the Texas Railroad Commission, reiterated these views in his address on the purpose and operation of laws prorating oil production.

Proration Difficulties Heard

After recounting the history of proration by state regulatory bodies, especially Texas, Colonel Thompson expressed the opinion that the threat of federal control has passed. He explained that legislation is enacted only in response to an insistent demand and that the cry for oil control acts has now ceased. Continuing, Thompson declared that changes in the economic status of the industry as well as the nation were given as another reason why there will be no further agitation for federal control.

Difficulties of state regulation were classed by Thompson as coming from two sources. One is that the conservation statutes are written by legislators, who have the whole of the voting public rather than the oil industry's personnel as their constituency. The other is a small group of oil producers who are not satified with proration orders and seek relief through the courts. When checked, these men turn to violation of both regulations and decisions of the courts.

California Problems

"Five men could sit down at lunch and in an hour agree upon an operating method by which the wasteful methods at Kettleman Hills North Dome could be halted and one of the valuable oil deposits of California conserved." Such was the charge hurled by A. L. Weil, president of General Petroleum Corporation, as a part of his summary of conditions on the West Coast. Weil took the place of Charles S. Jones, president of the California Oil & Gas Association.

He gave figures to show how conditions have changed in 10 years. In 1924 daily California production was 635,000 barrels, while today it is 636,000 barrels, but stocks have been reduced 37,000,000 barrels. Consumption 10 years ago was 1,100,000,000 gallons a year, and for 1935 will be close to 21,000,000,000 gallons.

Weil expressed the opinion that there is no hope of a California conservation statute within the next few years. Defeat of the Sharkey bill two years ago was presented as an indication that it is not logical to expect legislation of this nature.

O. D. DONNELL
Elected Treasurer of American Petroleum Institute

A.S.T.M. Standards on Petroleum Products

EACH year A.S.T.M Committee D-2 on Petroleum Products and Lubricants sponsors the publication under one cover of all A.S.T.M. standards pertaining to petroleum. The current edition, 1935, contains 57 test methods, six specifications and two lists of standardized definitions of terms, all of this material being given in its latest approved form.

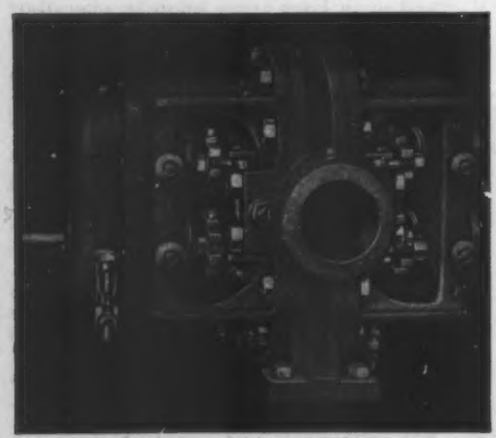
The current report of Committee D-2 comprises an interesting discussion of the work on the Sligh oxidation test with a proposed method of test for oxidation number of lubricating oils by the Sligh method and gives the revised Diesel fuel oil classification which is published for information.

A new method of test given for the first time covers the vapor pressure of motor and aviation gasoline (Reid method). During 1935 a number of the standard methods given in the compilation have been revised including those covering the following: test for dilution of crankcase oils, distillation of gasoline, naphtha, etc., ductility of bituminous materials, testing emulsified asphalts, flash point by means of the Tag closed tester. Changes also have been incorporated in the tests for residue of specified penetration, precipitation number of lubricating oils, viscosity by means of the Saybolt viscosimeter and water and sediment in petroleum products by means of the centrifuge.

In addition standards for the following subjects are detailed in the compilation.

Burning quality, carbon residue, cloud and pour points, color, distillation, flash and fire points, gravity, gum content, knock characteristics, melting point, neutralization number, loss on heating, penetration, saponification number, softening point, sulfur, viscosity.

Copies of this publication, 358 pages, heavy paper cover, can be obtained from A.S.T.M. Headquarters, 260 S. Broad Street, Philadelphia, at $1.75 per copy. Special prices are in effect on orders for 10 or more copies.



KINNEY MODEL A HELIQUAD PUMP

KINNEY MODEL B HELIQUAD PUMP

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users, who have kept a careful record of the cost of pumps and their upkeep, have reported that their Kinney pumps have given long periods of service without any breakdowns and with replacement part costs astonishingly low.

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Symposium on Heat Transmission

THE Division of Industrial and Engineering Chemistry of the American Chemical Society announces a Symposium on Heat Transmission to be held at Yale University, New Haven, Connecticut, on December 30 and 31, 1935. The program being arranged by the committee in charge is designed to attract engineers and chemists whose interests lie in the broad field of heat transfer, including both heat transfer by convection between fluids and solids, and heat transfer by radiation from gases and solids. It is expected that a large and representative group from various industrial concerns and universities will attend.

The previous Symposium on Heat Transmission held by the American Chemical Society was at the Washington meeting in 1924, under the chairmanship of W. H. McAdams. The symposium planned for December continues the policy inaugurated by the Division of Industrial and Engineering Chemistry with the Symposium on Distillation held at the Massachusetts Institute of Technology in December, 1934, of holding special meetings for chemical engineering symposia. The marked success of the latter meeting encouraged the continuance of the plan.

The committee in charge consists of D. B. Keyes, chairman, T. H. Chilton, B. F. Dodge, T. K. Sherwood (chairman pro tem). Those interested in submitting papers have been invited to communicate immediately with T. K. Sherwood, Massachusetts Institute of Technology, Cambridge, Massachusetts.

A.S.T.M Organizes Gaseous Fuels Committee

FOR some time the American Society for Testing Materials has been considering requests that it organize a standing committee to undertake certain standardization and research work in the field of gaseous fuels. After consultation with the interested parties a definite decision was reached to organize a formal committee. At a well-attended meeting during the annual gathering in Detroit, the committee was formally organized with the following personnel:

American Society of Mechanical En-

NEWEST! GASOLINE PLANT EAST TEXAS

HERE, in one of the newest and most up-to-date gasoline plants in East Texas, you see eleven COOPER-BESSEMER compressors! Each unit is a two-cycle Type-11 twin. The plant is that of Sabine Valley Gasoline Company.

IN selecting Cooper-Bessemer units for this modern plant, the Sabine people knew what they wanted — the best! It was not a question of price . . . instead, they considered the costs over a period of years. Performance has been even better than we expected! And the plant has exceeded its capacity guarantee by a wide margin.

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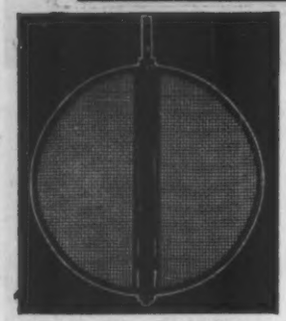
Esperson Bldg., Houston, Texas
Magnolia Bldg., Dallas, Texas
225 Crockett St., Shreveport, La.
201 East First St., Tulsa, Oklahoma



(Top)—Filter Leaf—Bottom Drain.
(Below)—Filter Leaf—Top Drain.

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. . . of a sturdier cloth that will last longer under the exacting requirements of contact filtration of oil . . . of a denser texture which will filter better and allow less fine clay to pass . . . with a welded type of attachment which eliminates rim leaks and rim corrosion . . . that can be easily flushed out frequently without removing from the press . . . which allows a larger clearance for dropped cake . . . with which it is not necessary to remove cloth from leaf until cloth renewal is needed—possibly a matter of years.

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C. E. Bales, Ironton Fire Brick Company;

Bethlehem Steel Company, E. F. Kenney;

Brooklyn Union Gas Company, J. F. Anthes;

G. G. Brown, University of Michigan;

R. M. Conner, American Gas Association, Testing Laboratory;

Corning Glass Works, W. W. Oakley;

Earle Derby, Standard Gasoline Company;

R. L. Dodge, duPont Ammonia Corporation;

H. L. Doherty & Company, H. D. Hancock;

A. C. Fieldner, United States Bureau of Mines;

J. V. Freeman, United States Steel Corporation;

W. H. Fulweiler, United Gas Improvement Company;

A. W. Gauger, Mineral Industries Research; Pennsylvania State College;

S. H. Graf, Oregon State Agricultural College;

R. B. Harper, Peoples Gas Light & Coke Company;

G. G. Oberfell, Phillips Petroleum Company;

D. A. Russell, Youngstown Sheet and Tube Company;

H. S. Smith, Carbide & Carbon Chemicals Corporation;

S. S. Tomkins, Consolidated Gas Company of New York.

Carl D. Ulmer, Koppers Construction Company;

National Bureau of Standards, E. R. Weaver;

J. C. Witt, Universal Atlas Cement Company.

Advisory member: T. R. Weymouth, Columbia Gas & Electric Corporation.

A. C. Fieldner, chief engineer, Experiment Stations Division, United States Bureau of Mines was elected permanent chairman of the committee; R. M. Conner, director, American Gas Association Testing Laboratory as secretary and R. B. Harper, vice president, The Peoples Gas Light & Coke Company, was chosen vice chairman. The advisory committee will consist of these three officers and Dr. G. G. Brown, University of Michigan; J. V. Freeman, United States Steel Corporation; and G. G. Oberfell, Phillips Petroleum Company. The personnel of the committee is being enlarged to provide for representation of other groups and industries.

Careful consideration was given at the meeting to a preliminary program of work which had been drawn up by the secretary for consideration. The main subjects selected for immediate development by the committee are as follows:

Collection of Samples;

Measurement of Samples;

Calorific Value;

Specific Gravity or Density.

Subcommittees are now being developed to institute work on these various projects. It is expected these groups will be appointed in the very near future and that when certain details are developed actual work will get under way.

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AGENTS IN ALL PRINCIPAL CITIES

Gasoline Pipe Line Completed

CONSTRUCTION of the Keystone Pipe Line Company's 165-mile, six-inch gasoline line extending from a point near Mechanicsburg to Pittsburgh, Pennsylvania, was completed early in November. The east half of the line was completed and tested during October and filled with gasoline to a point below Altoona. Keystone Pipe Line Company also started work recently on a 15-mile branch line from its new trunk line extension and other such short lines are planned so as to tie in with cities adjacent to the system. The company is a subsidiary of The Atlantic Refining Company and handles gasoline produced by that company's Philadelphia refinery. Completion will bring about marked decreases in refining at the company's Pittsburgh and Franklin, Pennsylvania, plants.

Warren Petroleum Buys Amerada Gasoline Plants

WARREN PETROLEUM COMPANY last month announced that its subsidiary, Natural Gasoline Corporation, had purchased all of the natural gasoline plants, equipment and natural gasoline production of Amerada Petroleum Corporation in Oklahoma and Texas. The purchase involved six plants in Oklahoma and one in Texas, the combined capacity of which is approximately 158,000 gallons daily or about three times the present daily production. Change of ownership became effective on October 1.

M. E. Mockley, who came with Amerada Petroleum Corporation at the time its first gasoline plant was built and has been general manager of the natural gasoline division of the company for the past 14 years, will be with the new organization as vice president in charge of operations. Other officials of Natural Gasoline Corporation are W. K. Warren, president; J. A. LaFortune, vice president; H. E. Felt, secretary, and A. J. Murphy, treasurer. All but one member of Mockley's staff and the entire field personnel have been taken over. H. W. Hartz will continue as Mockley's assistant and W. A. Baden of the Warren organization will join Natural Gasoline Corporation. All casinghead gas rights of Amerada Petroleum Corporation in the new Monument field of Lea County, New Mexico, are included in the transaction. In addition contracts are being signed with other operators in that area and the new company plans erection of a large natural gasoline plant in that field.

W. K. WARREN

Unfired Pressure Vessel Code Undergoing Revision

THE joint A.P.I.-A.S.M.E. Code for Design, Construction, Inspection and Repair of Unfired Pressure Vessels for Petroleum Iiquids and Gases, prepared in and published in 1934 by a joint committee of the American Petroleum Institute and the American Society of Mechanical Engineers, is now undergoing revision. This code has become widely used by the petroleum industry. The joint committee now is engaged in the preparation of a revision which probably will include a new section on integrally-forged vessels. The five sections of the revised code will be, Section W, Fusion-welded unfired pressure vessels, Section R, Riveted unfired pressure vessels, Section F, Integrally-forged pressure vessels, Section I, Inspection, repair, and allowable working pressures for unfired pressure vessels and Section S, Material specifications. It is expected that the second edition will be available near the end of this year.

Penn Grade in Sealed Drums

STEPS to protect export shipments of motor oil marketed by its members were taken by the Pennsylvania Grade Crude Oil Association through recent adoption of a new regulation. The new ruling, governing the method for export shipments, is designed to prevent substitution or adulteration of the contents of drums or barrels destined for overseas consumption.

All such drums and barrels will hereafter be sealed with metal closures covering both openings. The closure seals will bear the emblem of the association lithographed in blue and gold and are of such construction that it is impossible to open the container without destroying the seal. The permit number, assigned to that brand of oil by the association will appear on the seal to identify the supplier.

Arc Welding Handbook

THE "Procedure Handbook of Arc Welding, Design and Practices," third edition, has been published by The Lincoln Electric Company, Cleveland, Ohio. This edition is considerably larger than the previous one. The new volume contains 586 pages, is encyclo-

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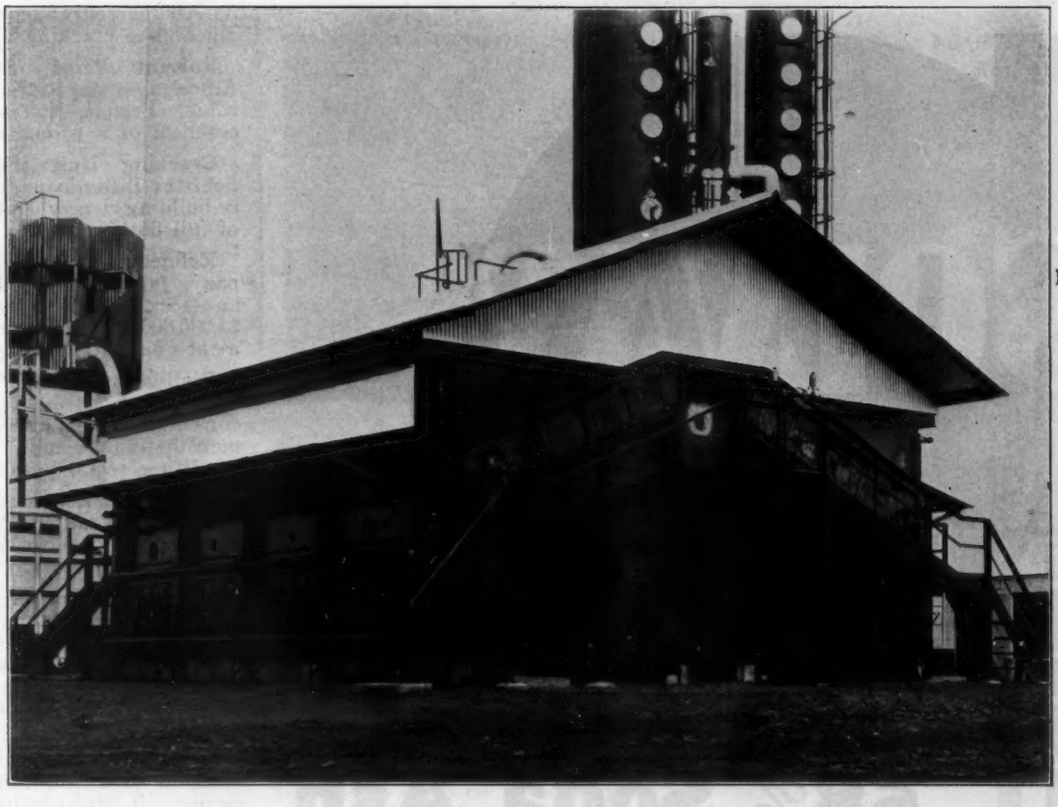

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pedic in scope and contents, and is divided into eight princpal sections that deal with important phases of arc welding. The text has more than 700 illustrations. The different sections of the book describe welding methods and equipment, technique of welding, procedures, speeds and costs of welding mild steel, structure and properties of weld metal, weldability of metals, design for arc-welded steel construction, designing for arc-welded structures and a thorough treatment of typical applications of arc welding in manufacturing, construction and maintenance, and advertising section. Copies will be mailed to any address in the United States for $1.50 each.

▼ PLANT ACTIVITIES ▼

Improvements: London and Thames Haven Oil Wharves, Ltd., Thames Haven, Essex, England, plans extensions to its existing refinery, with contract to Foster Wheeler Corporation.

Improvement: Worringham, Edward & Company, Ltd., Deptford, S. E. 8, England, plans to completely rebuild its lubricating oil refinery.

Improvements: Anglo-American Oil Company, Ltd., Port Ellesmere, England, has announced that it will install some additional new units, including specialty plant, contract for the latter to Alco Products, Inc.

Improvements: Curacaosche Petroleum Ind. Mij. Willemstad, Curacao, D. W. I., is constructing additional cracking and naphtha reforming units and is generally modernizing its 165,000-barrel refinery.

Refinery: Iraq Petroleum Company plans erection of a new refinery at Baba Gurger, near Kirkuk, Iraq, contract to Foster Wheeler Corporation for stabilization units.

Improvements: Assam Oil Company, Digboi, India, is enlarging capacity of its 7000-barrel refinery and reconstructing Dubbs cracking units.

Solvent Plant: Standard Franco-Americaine de Raffinage, at Port Jerome, France, is reported planning erection of a propane dewaxing plant.

Cracking Unit: Societe Tyonnaise Schistes Bitumineux, at Auton, France, is building a new Dubbs cracking unit of full flashing type.

Refinery: Korean Petroleum Company, Japan, has been formed by Japanese interests with reported capital of $3,000,000 and contemplates establishment of a petroleum refinery in Korea.

Distillation Unit: "Galicja" Spolka, Akcyjna at Drohobycz, Poland, is to construct a new atmospheric and vacuum distillation unit. Contract to Foster Wheeler Corporation.

Refinery: Zeilenievski & Fitzner Gamper at Krakow, Poland, is building a new refinery with contract to Foster Wheeler Corporation.

Distillation Unit: Romano-Americana (subsidiary of Standard Oil Company of New Jersey) is reported planning erection of a new tube still distillation unit, a stabilization system and phenol solvent refining process at Ploesti-Teleajen, Roumania.

Improvements: Steaua Romana plans erection of a new tube still for lubricating oil manufacture at Campina, Roumania, with contract to Arthur G. McKee Company, and two Braun stabilization units.

Refinery: Campsa (Spanish Petroleum Monopoly) is reported planning erection of a new refinery at Santander, Spain.

Shale Oil Plant: South African Torbanite Mining and Refining Company, at Ermelo, Transvall, Africa, is building a 1000-barrel distillation unit for handling shale oil.

Improvements: Agwi Petroleum Corporation, Ltd., Fawley, England, plans addition of a new stabilization system and an Edeleanu solvent refining plant.

Construction: Societe Anonyme des Petrole Jupiter, at the Pauillac and Petit Couronne (near Rouen) refineries, France, is building Dubbs reforming units and Dubbs full flashing cracking units at each refinery.

Cracking Unit: Fanto-Werke A. G., Pardubice, Czechoslovakia, at its 4000-barrel refinery is reported planning erection of a new cracking unit in the near future.

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Refinery: Comet Oil Refineries, Ltd., Montreal, Canada, is progressing rapidly with construction of its 2700-barrel topping plants and 2280-barrel Dubbs cracking unit.

Refinery: Yacimientos Petroliferos Fiscales (Argentine Government Oil Fields), Buenos Aires, Argentina, is reported planning establishment of a small refinery for the Mendoza oilfield district.

Gasoline Plant: Natural Gasoline Corporation (subsidiary of Warren Petroleum Company), which recently purchased the six gasoline plants of Amerada Petroleum Corporation, plans to erect a new gasoline plant in the Monument field, Lea County, New Mexico.

Hydrogenation: Hydierwerke A. G., formed by The Prussian State Collieries of the Ruhr, Germany, is installing a large process for production of motor fuel from coal. The new hydrogenation plants will increase capacity to 90,000 tons annually.

Carbonization Plants: Braunkohle Benzine Company, Germany, is building plants at Doehlen near Leipzig and near Madgeburg, for production of gasoline from lignite. These plants will use low temperature carbonization of tar.

Operating: Pettus Refining Company, Mathis, Texas, had completed construction work and placed the 1000-barrel skimming plant in operation. Plans call for a pipe line to the Live Oak County fields in the near future. Roy Mechen, general superintendent.

Gasoline Line: Keystone Pipe Line Company, subsidiary of The Atlantic Refining Company, has completed construction of a 165-mile six-inch gasoline pipe line extending from Mechanicsburg to Pittsburgh, Pa. The company is putting in several short branch lines from its main trunk system to adjacent cities.

Refinery: Coastal Refineries, Inc., is completing work on its 5000 barrel refinery at Port Isabel, near Brownsville, Texas. Company is affiliated with Valley Pipe Line Company which has completed an 88-mile pipe line from Samfordyce field to Port Isabel.

Enlarge: Tyreco Refining Company, Arp, Texas, has purchased Anarene Refining Company's 200-barrel skimming plant, located near Anarene, Archer County, Texas, and will enlarge to about 1000 barrels daily. The company operates two plants in the East Texas field.

Gasoline Plant: Breckenridge Gasoline Company has suspended operations at its natural gasoline plant in southern Stephens County, Texas, owing to shortage of gas supply. Gas contracts have been assigned to Hanlon Gasoline Company.

Treating Plant: Wilshire Oil Company, Santa Fe Springs, California, has let contract to Stratford Engineering Corporation for installation of a 5000-barrel Contactor Centrifuge Cold Treatment plant for acid treating pressure distillation from its new Dubbs unit now building. Plant will include mechanical refrigeration for cold treating, Stratco contactors for dispersion and intimate mixing and direct driven centrifuges.

▼ BUSINESS NOTES ▼

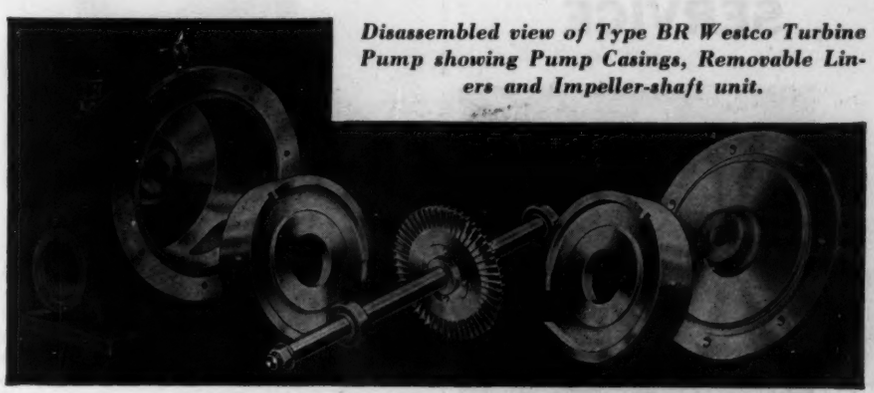
DR. HANS TROPSCH, associate director of research of Universal Oil Products Company, Chicago, and one of the world's great research chemists, died October 8 in Essen, Germany, after an illness of several months.

Dr. Tropsch was a world authority on coal and oil chemistry, particularly catalytic hydrogenation of carbon monoxide from coal to produce gasoline and other oils.

He worked with Franz Fischer in developing a process to make motor fuel from carbon monoxide and hydrogen, and plants are now being built in Germany to operate this process.

Born October 7, 1889, Dr. Tropsch was graduated in 1912 from the German Technische Hochschule in Prague, and received his doctor's degree from the same school in 1913.

From 1920 to 1928 he was associate director of the Kaiser Wilhelm Institute for coal research, in Mulheim-



Disassembled view of Type BR Westco Turbine Pump showing Pump Casings, Removable Liners and Impeller-shaft unit.

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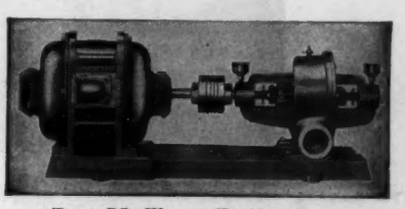

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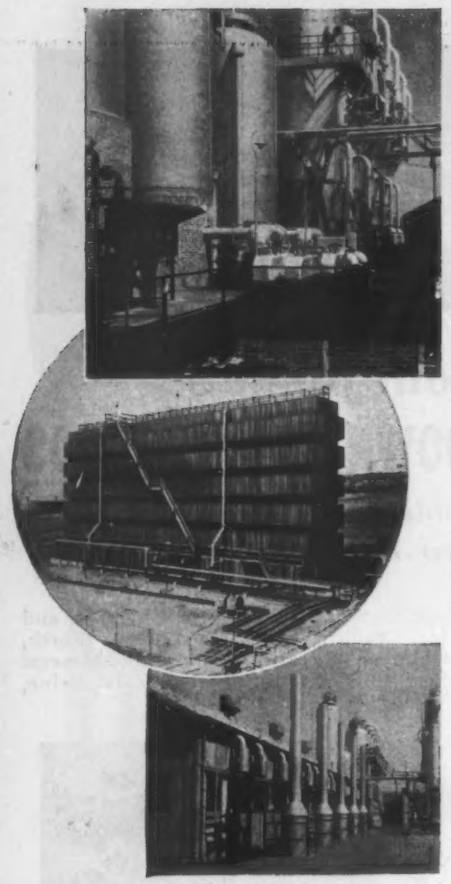

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DR. HANS TROPSCH

Ruhr. In the latter year Dr. Tropsch was commissioned by the Czechoslovakian government to organize and head a national coal research institute in Prague. He was director of that institute until 1931 when he came to this country to join the research staff of Universal Oil Products Company.

In addition to his work with Universal Oil Products Company, he was also professor of chemistry at the University of Chicago and at Armour Institute, Chicago.

COLONEL WILLARD F. ROCKWELL, president of Pittsburgh Equitable Meter Company, Merco Nordstrom Valve Company of Oakland, California, and Timken Companies of Detroit, has just completed a trip from coast to coast, visiting the various plants operating under his direction. Because of the widely diversified markets for the products and equipment manufactured by these companies, he obtains a broad outlook on industry as a whole. His optimism over present business conditions is shown by the fact that expenditures in the various plants which he heads have been authorized to the extent of over a million dollars.

The rapidly expanding export business of these several companies has necessitated Colonel Rockwell's visit to South and Central America at this time. His return to the Untied States, via the Pacific Coast, is planned to enable him to attend the American Petroleum Institute at Los Angeles.

ELECTION of John D. Swain as vice president of Electro Metallurgical Sales Corporation was announced October 2. He has been vice president of The Linde Air Products Company and Union Carbide Sales Company, which are other units of Union Carbide and Carbon Corporation. He has been actively connected with these units for 20 years. His offices will be in the Carbide and Carbon Building, 30 East 42nd Street, New York.

NEARLY 100 field service representatives of Oakite Products, Inc., will meet at the headquarters office in New York, December 9 to 13, 1935 in connection with the annual technical sales conference. A large number of technical papers will be read dealing with the technical cleaning problems of many different industries. Mechanical improvements in production equipmet that have occurred during the past year have, in turn, made necessary many changes in cleaning methods and materials and the interchange of ideas developed through the technical discussions at this coming conference, puts each Oakite field representative in a position where he can be more helpful to the industries he serves.

W. S. BAYLIS has announced his withdrawal from Filtrol Company of California. Baylis, who for over 20 years has been active in the development of refining processes for animal, vegetable and mineral oils, has had numerous patents issued in his name. As one of the founders of Filtrol Company of California over 14 years ago, he has been identified as a leader in the manufacture of acid-activated clays and adsorbents. He has not announced for the immediate future, although it is intimated that he will continue to be identified with the petroleum industry.

JOHN PRIMROSE, who has been vice president of Foster Wheeler Corporation since it was organized, has been elected vice chairman of the board, following the resignation of Pell W. Foster, who will continue as a director. In 1901 Primrose became chief engineer of Power Specialty Company and subsequently vice president in charge of oil refinery activities. When Foster Wheeler Corporation was formed he was elected a vice president, which office he has held to the present. Through these associations he has become well known in the oil refining industry in this country and abroad.

JOHN PRIMROSE

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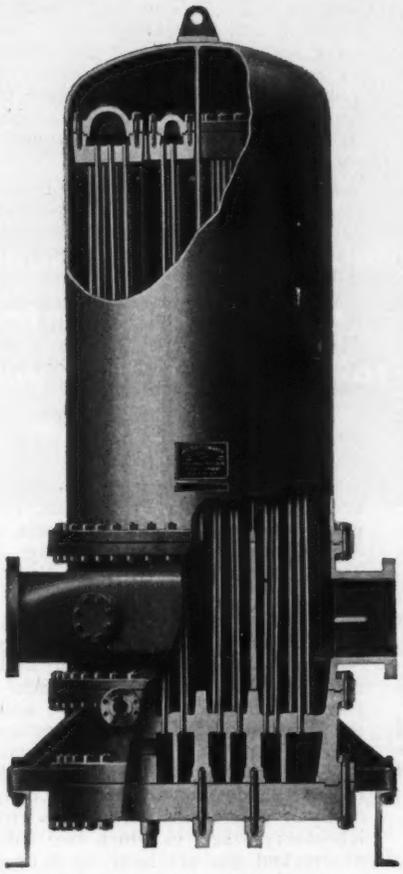

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ROBERT CHELSTROM, New England representative of Oster-Williams, Cleveland, Ohio, was killed in an automobile accident, October 18, while returning to his home in Boston, from a trip to Connecticut. He was 59 years of age at the time of his death. Chelstrom joined the sales organization of The Oster Manufacturing Company in 1924 and when this organization merged with Williams Tool Corporation in 1929 he continued as New England representative for both, handling the combined lines of threading tools and machines.

HAVING returned to the United State after a sojourn of a year and a half as instrument and process engineer for refineries in Netherlands West Indies, Robert E. Rogers, Jr., has rejoined the engineering-sales staff of the New York office of The Foxboro Company, Foxboro, Mass. Rogers first became identified with The Foxboro Company in 1930, and was connected with the Tulsa and New York offices, serving Mid-Continent and Eastern process industries, before leaving for the Indies early in 1934.

FRANK F. CHILES, formerly manager of sales of the Bar Division of Corrigan, McKinney Steel Company, has been appointed assistant manager of sales of the Bar Division, Republic Steel Corporation, with headquarters at Youngstown, Ohio. In his new capacity, Chiles will assist W. F. Vosmer in supervising the sales of all carbon semi-finished steel bars, shapes and plates produced by Republic Steel Corporation.

AN exhibit showing the actual making of oil testing instruments will be seen at the International Petroleum Exposition of Tulsa May 16 to 23, 1936, according to W. A. Schlueter, chairman of the scientific and technical committee who announces that the committee has arranged for C. J. Tagliabue Manufacturing Company to bring more than $50,000 worth of equipment and a half dozen operators to the exposition.

This glass blowing exhibit will show the making of hydrometers, colorimeters, chronometers, burning test gauges, emulsion apparatus, viscometers, cloud pour and test apparatus, corrosion and gum testing, petroleum melting point apparatus, ring and ball tester, distillation apparatus, sulphur determination apparatus, and many other instruments used in the oil industry.

L. S. GREGORY COMPANY, Consulting Engineers, 2221 N. Denver Place, Tulsa, Oklahoma, has been appointed exclusive licensing agent for the Perco process of chemical refining, formerly termed the "copper sweetening" process. The process was perfected after several years development work by Petroleum Engineering Research Company, a subsidiary of Phillips Petroleum Company. The process is reported to be adaptable to sweetening or treating natural gasoline, straight-run naphtha, cracked gasoline or vapor recovery gasoline.

RALPH M. Parsons has moved the main offices of his company to 310 S. Michigan Avenue, Chicago, from Mount Vernon, Ohio, which has been head quarters since its organization a year ago.

Ralph M. Parsons Company is an engineering and contracting organization, devoted primarily to work in the oil refining field, specializing in the design and construction of large and small Dubbs cracking and reforming units. The company recently completed the construction of a 750-barrel special Dubbs cracking unit at the plant of the Home Oil Refining Company, Great Falls, Montana, and is now installing additional equipment there.

It is also building a 12,500-barrel complete refinery, of which the primary feature is an 8000-barrel Dubbs cracking unit, for Wilshire Oil Company of Los Angeles.

Parsons is also starting work on a 700-barrel special Dubbs cracking unit for Malco Refineries, Inc., Artesia, New Mexico, and has two other Dubbs cracking units under contract.

The change of headquarters necessitated the moving of some 40 people from Mount Vernon to Chicago.

Parsons will continue to maintain offices at 4800 Santa Fe Avenue, Los Angeles, in charge of Milton Lewis, and at 815 Tower Petroleum Building, Dallas, Texas, in charge of Allen M. Peairs.

GEORGE B. MURPHY, manager of the research and development laboratories of Universal Oil Products Company, Chicago, on October 9, addressed the Institute of Chemical Engineers at Chicago, on "Catalytic Polymerization as a Means of Producing Motor Fuel." He traced the development of his company's catalytic polymerization process from the laboratory stage, in which two cubic feet of cracked gas per hour were processed, up to the present successful large-scale commercial stage where polymer gasoline is produced at the rate of five gallons or more per 1000 cubic feet of gas processed.

THE Hancock Valve Division of the Consolidated Ashcroft Hancock Company, Bridgeport, Connecticut, announces the recent appointment of the Moorlane Company and Frick-Reid Supply Corporation, both of Tulsa, Oklahoma, as stock-carrying jobbers.

Malcolm Black has recently completed a four months training course at the Bridgeport and Boston plants of Consolidated Ashcroft Hancock Company and has been added to the Tulsa office of this company. Black has had several years of practical experience in and is well known to the Mid-Continent oil industry.

Effective Thursday, October 10, the Pittsburgh district sales office of Republic Steel Corporation removed from 4th and Bingham streets, S. S., to 1832 Oliver Building, Pittsburgh, Pennsylvania. The phone number of the offices in the Oliver Building is Grant 2425. F. M. Welsh continues in charge of the office, assisted by his present staff.

Union Drawn Steel Company, a Republic Steel Corporation subsidiary, moved into an adjoining suite in the Oliver Building. W. C. Gullyes, district sales manager is in charge.

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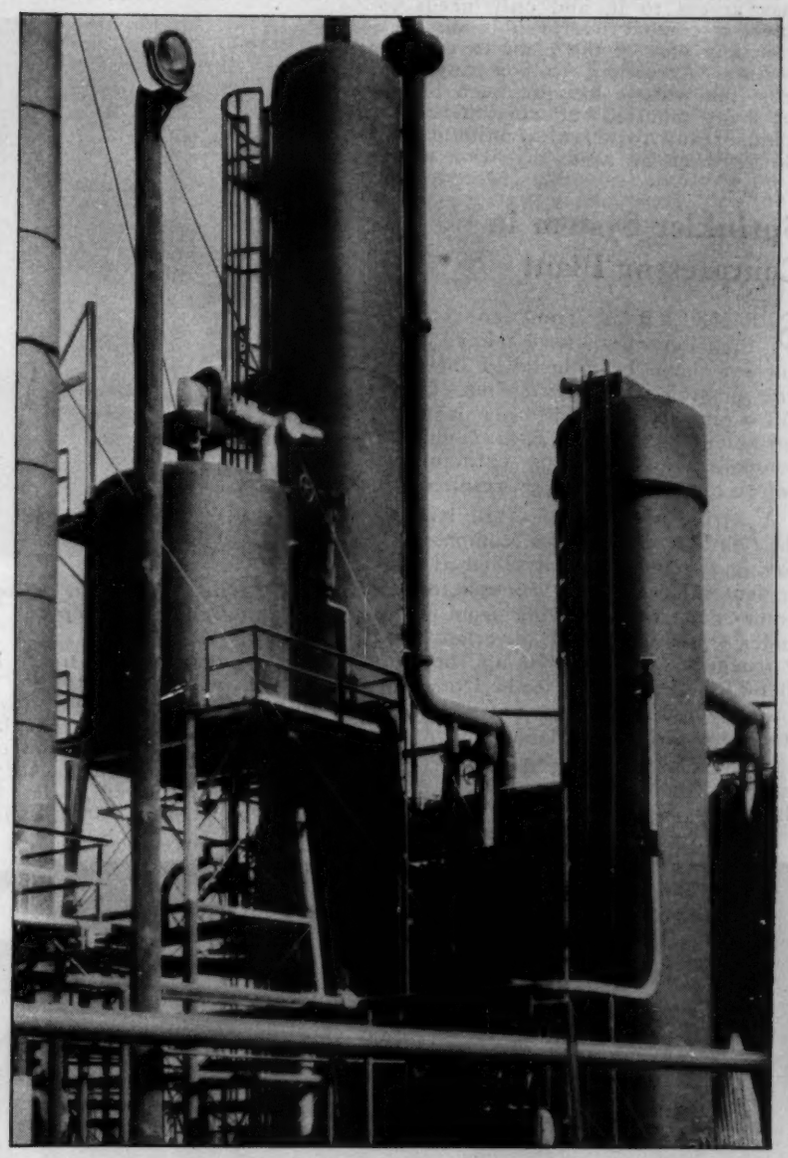
Typical insulating job planned by the Eagle-Picher Contracting Division. This topping unit was insulated with Eagle Blankets, Eagle "66" Plastic Insulation and Eagle Insulseal (waterproofing cement). Pipes were insulated with Eagle "77" Pipe Covering and Eagle "55" Block Insulation.



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Eagle "77" Pipe Covering. Insulating wool felted and secured, flexible and easily applied. Particularly adapted for hot lines where a cement finish is desired.

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▼ IDEAS ▼

First Aid Call

EVERY one connected with an oil refinery realizes the hazards connected with the various operations, but when an employee becomes injured, unless some other person is nearby, he sometimes finds it difficult to attract the attention of the proper person to administer first aid.

In the plant of Freedom Oil Works Company, Freedom, Pennsylvania, is a whistle which is to be used only when an employee is in need of first aid. The whistle valve is placed near the change room, where a man has easy access to it, and only needs to travel a comparatively short distance from any part of the plant to call assistance. According to company records, the whistle has not been blown for many months, but, nevertheless, it stands ready to serve an injured employee when he needs attention most.

Sprinkler System in Compressor Plant

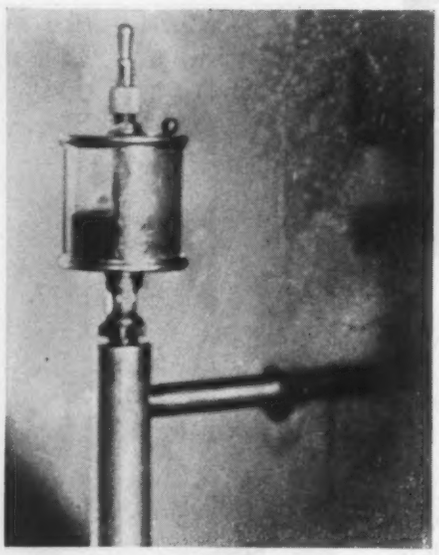
SPRINKLER systems to control fires have been used many years, but few have been installed in gasoline plant compressor rooms. Union Oil Company of California installed sprinkler systems so fires could be controlled and perhaps extinguished before extensive damage resulted.

A series of pipe lines are laid on the girders above the compressors, having spray nozzles attached at convenient intervals, near enough to each other that water falling from them under pressure will overlap and thoroughly wet everything beneath them. A feed line leads from the boiler pump discharge so that constant pressure is available.

If fire should occur, the boiler fireman or other employe nearby can set the sprays in operation by opening a valve near the boiler battery, and designated by a painted board showing just what to do and when to do it. The expense of this installation is nominal, and can be built of salvaged material throughout, including sprays, pipe and valves. J. C. A.

First-Aid for Lubricator Glass

WHEN a careless oiler cracked the glass on the lubricator supplying the pin bearing on an oil pump, it looked like he would have to stand by



Shellac and Paper Make Emergency Repair

with the pump can and try to keep up a supply of lubricant to the bearing until a replacement could be obtained.

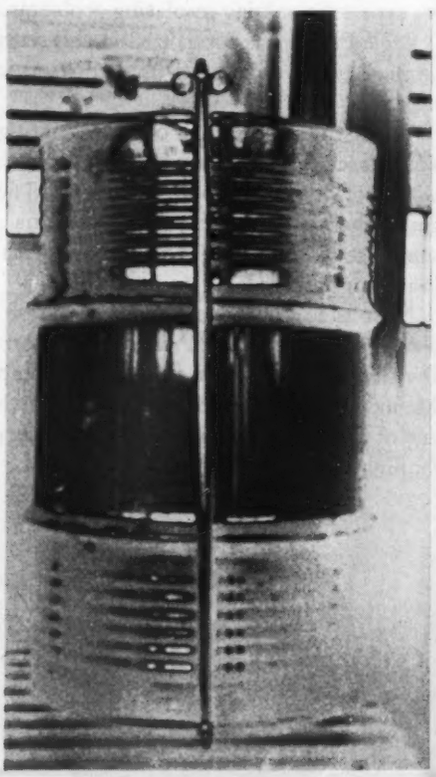
Fortunately, however, the glass was not all broken out, and the engineer was able to make an emergency repair which stood up even better than he had anticipated. Cleaning the glass with gasoline, he fitted the larger parts together jig-saw puzzle style, and coated them on the outside with shellac, which he had allowed to dry until very "tacky". Around these pieces of glass, and lapping over onto the uninjured portion of the cylinder, was pressed a piece of ordinary bond paper, also coated on the inner side with nearly dry shellac.

In a very few minutes the shellac hardened sufficiently to allow the lubricator to be refilled with oil and again put on the job. Some days later, when it became apparent that a replacement glass would be a long time arriving, the paper was given a coat of aluminum paint—and that same patched lubricator, although now moved away from such a conspicuous spot as it occupied when broken, is still serving the purpose, three years after the supposedly temporary repair.

ELTON STERRETT,
Longview, Texas.

Barrel Sampling Device

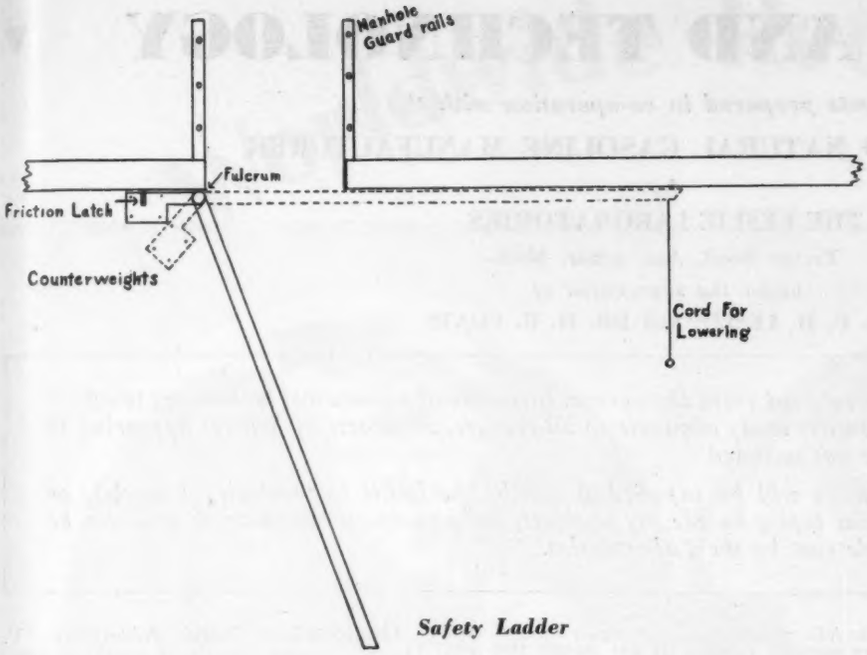
IN order to forestall any cause for complaints by customers on account of minute quantities of moisture in barrels of finished oils, Freedom Oil Works Company, Freedom, Pennsylvania, developed a barrel sampling device which not only samples the oil from any depth, but the moisture or water settled to the bottom of the drum may be easily withdrawn.



Sampling Device

The instrument was made from a piece of smooth seamless copper tubing, drawn to a small orifice at one end, and fitted with finger holes at the other. The operator, when inspecting a filled barrel before it is sealed, introduces the sampler into the bung hole, and, with the barrel tipped to one side as it travels down the automatic conveyor, is able to draw a sample from the drum, as well as to remove all of the moisture.

The Sprinkler System in the Compressor Plant, a novel idea in fire fighting, is controlled at this point.



Safety Ladder

Counterbalanced Safety Ladder

LACKING storage space in the plant machine shop, it was decided to use an attic overhead for this purpose. Entrance to the attic had to be effected by means of a ladder, which, because of overhead lineshafts and belts, was necessarily located in such position as to be unsafe and inconvenient as regards passing between the various machines on the floor. This difficulty was finally overcome by constructing a counter-weighted ladder, similar in design to the counterbalanced stairways often used on the fire escape systems of large buildings.

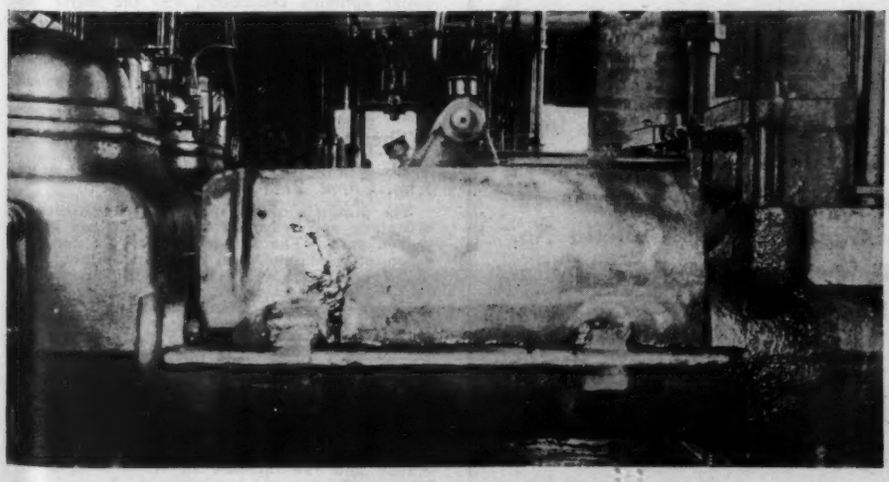
When not in use this ladder, due to the heavy counterweights, automatically raises itself out of the way. A heavy piece of cord attached to its foot and hanging within hands' reach of the floor allows it to be lowered when needed. If desired, a friction latch may be made from a piece of stout spring which will hold the ladder in its lowered position until given an upward push by hand. Counterweighting was effected by bolting heavy iron and lead weights to the upper side of the fulcrum. Light weight ladders of this type may be cheaply constructed, and offer a safe and convenient means of access to difficulty situated lineshaft bearings and elevated valves.

RUSSELL M. LILLY.

Pump Piston Rod Guard

OPERATORS will step on the side of pumps when checking speed of operation, and sand and dirt is wiped off the soles of shoes when so doing. To prevent dirt accumulating from this source, a guard was designed and applied to pumps in the plant of McClanahan Refineries, Inc., at St. Louis, Michigan.

This guard is constructed from light tank roof steel, with clips welded to one side, made so they would fit over the rolled rim of the sides of the pumps. Use of this guard serves a double purpose; that of preventing dirt from being scraped into the drain lines in the foundations of the pumps, and onto the piston rods, and also prevents the operator from getting into such difficulites as having his foot caught between the rocker shaft arm and the pump ends.



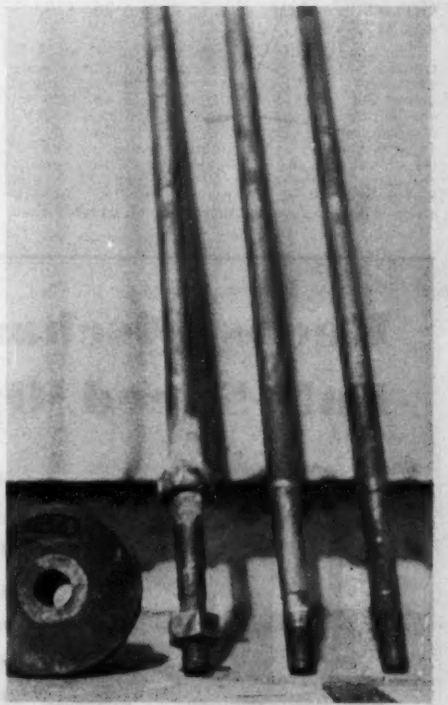
Pump Piston Rod Guard

Eliminating Pump Shut-downs

RODS on the pumps handling cooling water for a battery of gas engines gave trouble almost from installation. Due to impurities in the water, brass rods were specified after corrosion promptly ruined the steel rods furnished with the units.

Corrosion was minimized, but the design of the rod proved too light for the service, as after only a short term of operation the cast iron piston heads would work back over the shoulder on the brass which was supposed to afford backing for the adjusting nut, and a noticeable thump would occur each time the rod reversed direction.

Examination of the rods showed that under load the narrow lip or shoulder had sheared off, pressure in one direction forcing the head back onto the rod, then pulling it free, only to ram it on even further with the next reversal; literally swaging the rod under repeated hammer-like blows until the packing would work off the piston and the pump fail.



Right: Original rod; Center: One failed in service; Left: next to piston head, built-up boss that made good.

With a welder's torch, brass was built up around the rod at the point where the shoulder originally stood, and this big boss squared off with a file on the side against which the piston was to be clamped. These built-up rods, costing for their repair less than transportation charges on new ones, withstood the heavy duty demanded of them, and now last until the gradual wear at the packing gland reduces the section there below a practical diameter.

ELTON STERRETT,
Longview, Texas.

SCIENCE AND TECHNOLOGY

Abstracts prepared in co-operation with the

REFINER AND NATURAL GASOLINE MANUFACTURER

by

THE LESLIE LABORATORIES

Traver Road, Ann Arbor, Mich.

under the supervision of

DR. E. H. LESLIE and DR. H. B. COATS

The abstracts here presented are selected from the current literature of science and technology to afford reference to fundamental information not easily available to all readers. Abstracts of articles appearing in readily obtainable trade journals are not included.

Photostat copies of original articles will be supplied at cost by the Leslie Laboratories. Complete or limited bibliographies covering special topics by tile, by abstract, or in complete manuscript, will also be prepared and furnished at reasonable cost by the Laboratories.

Fundamental Physical Data:

Conduction Through Transformer Oil at High Field Strengths. J. F. GILLIES. *J. Inst. Elect. Eng.*, **76** (1935) pp. 647-55.

The conductivity and power factor of an A-30 transformer oil dried over calcium turnings were measured. Under direct stresses above 50 and below 300 volts per mil, the relation between conduction current (I) and applied voltage (V) is given by the equation $I = kV^m$, where $m = 3$ (approximately). A minimum value of 4×10^9 megohms per cc. was assigned to the specific resistance of the oil at 50 volts per mil, but at higher stresses R decreases rapidly. At low stresses the D.C. resistance is much greater than the A.C. resistance, but at higher stresses the two approach equality. It was thought that the results may be explained by a theory of ionization by collision at high stresses.

Conductivity-Temperature Studies on Paraffin Waxes. W. JACKSON. *Trans. Faraday Soc.* **31** (1935) pp. 827-35.

The direct current conductivity of the several waxes studied had a negative temperature coefficient over a 5° to 10°C. range, located 10° to 15° below the melting point. It was thought that this is occasioned by a transition in crystalline structure occurring in this temperature range. The dielectric absorption passes through a maximum. The apparatus used for determining conductivity, comprising a triode tube, and capable of measuring resistances of 10^{13} ohms, is described.

Hydrocarbon Bond Additivity. V. DEITZ. *J. Chem. Physics* **3** (1935) p. 436.

Heats of hydrogenation are calculated for propylene, 1-butene, isobutene, cis-2-butene and trans-2-butene.

Molecular Latent Heats. J. D. HUFFINGTON. *Phil. Mag.* **19** (1935) pp. 836-40.

The author describes a quantity that is more nearly constant than that of Trouton's ratio. This quantity is the work done in producing the observed decrease in volume when one mol of vapor is condensed at the boiling point, divided by the boiling point in absolute degrees. An equation to express the similarity of form of the fields about the different molecules at a point of phase-change is derived.

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Chemical Compositions and Reactions:

Pyrolysis and Polymerization of Gaseous Paraffins and Olefins. F. W. SULLIVAN, JR., R. F. RUTHRUFF AND W. E. KUENTZEL. *Ind. Eng. Chem.* **27** (1935) pp. 1072-77.

Results obtained by cracking ethane and propane at atmospheric pressure in helical KA2S tubes are given. Under the best conditions about 74 percent by volume of the ethane charged was converted to olefins, and the maximum yield from propane was 82 percent. Ethylene and propylene were polymerized under conditions in the pressure range 500 to 3000 pounds per square inch and in the temperature range 650°F. to 850°F. Times of contact from 1 to 105 minutes were used. Based on the ethylene charged, liquid yields of 70 to 80 percent were obtained under optimum conditions, and the major portion of the liquid so made fell within the boiling range of gasoline. 60 to 65 percent of propylene was converted to liquid under optimum conditions. The data are given in detailed tabular form, and curves showing the results under different conditions are presented.

Thermal Decomposition of n-Pentane. J. J. MORGAN AND J. C. MUNDAY. *Ind. Eng. Chem.* **27** (1935) pp. 1082-86.

The products of the thermal decomposition of n-pentane are hydrogen and at least six hydrocarbon gases. The authors studied the decomposition of n-pentane, and n-pentane diluted with steam in a silica reaction chamber and without the presence of catalysts. At 600°C. the rate of decomposition of n-pentane was found to be independent of concentration over the range from one to one-sixth atmosphere. This indicates that the primary reaction is essentially one of the first order. Proportions of methane, propylene, propane, and 1-butane, are not affected by decrease of partial pressure. However, the amount of ethane decreases and the amount of ethylene and hydrogen increases with decrease of pressure. At higher temperatures the decrease in ethane and the increase in ethylene upon dilution with steam is also marked. There is evidence of the formation of 1,3-butadiene and of

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acetylene at temperatures of 700° to 800°C. Dilution with steam appears to favor the formation of acetylene.

Some Thermal Reactions of Hydrocarbon Gases. F. I. L. LAWRENCE. *Jour. Inst. Pet. Tech.*, **21** (1935) pp. 790-815.

The author reviews and discusses the literature of the thermal reactions of hydrocarbon gases containing two to four of carbon atoms. The thermal decomposition of paraffins and olefins is considered both empirically and theoretically. The breaking of the carbon-carbon bond at almost every conceivable place appears possible, as well as dehydrogenation to the corresponding olefin. The formation of polymers, or other liquid reaction products, at elevated temperatures is considered. Liquid yields up to 25 percent by weight have been obtained by the thermal decomposition of paraffins, and up to 40 percent by weight from olefins. The ultimate practical yield that can be obtained from a gas comprising 50 percent olefins and 50 percent paraffins appears to be of the order of 50 percent by weight of liquid products. The thermal reaction of hydrogen with hydrocarbons appears to be a direct factor in the lowering of the ultimate yield of liquid products. Some surfaces, such as iron, nickel, and graphitic carbon, promote decomposition of the gaseous hydrocarbons into their elements either directly or indirectly. A bibliography of 101 references is appended.

High-Temperature Pyrolysis of Gaseous Paraffin Hydrocarbons. H. TROPSCH AND G. EGLOFF. *Ind. Eng. Chem.* **27** (1935) pp. 1603-67.

At 1400°C. and 50 mm. pressure methane required 10 to 20 percent longer contact time than ethane and propane to obtain maximum yields of acetylene. At 1100°C. and 50 mm. pressure, with a contact time of 0.0035 seconds, ethane gave a maximum yield of 66 liters of ethylene per 100 liters of ethane. At 1400°C. substantially the same yield was obtained with a contact time of 0.0004 seconds. At 1100° the maximum yield of acetylene was 10 liters, while at 1400°C. 53 liters was obtained. Propylene was formed in the amount of 8 and 5 liters respectively, at 1100°C and 1400°C. At 1100°C. and 50 mm. pressure with a contact time of 0.008 seconds, propane gave a maximum yield of ethylene of 69 liters. At 1400°C. the maximum ethylene yield was 72 liters per 100 liters of propane, with a contact time of 0.005 seconds. The maximum yield of propylene was 15 liters. Acetylene yield was 25 liters per 100 liters of propane at 1100°C., and 76 liters at 1400°C. At 1100°C. and a contact time of 0.0035 seconds, n-butane yielded 94 liters of ethylene. The maximum acetylene yield was 30 liters, and propylene yield 22 liters per 100 liters of n-butane charge. Data are also given for isobutane.

Cracking and Polymerization of Low Molecular Weight Hydrocarbons. P. K. FROLICH AND P. J. WIEZEVICH. *Ind. Eng. Chem.* **27** (1935) pp. 1055-62.

The thermal decomposition of methane, ethane, propane, n-butane, the corresponding olefins, and acetylene is discussed from the viewpoint of maximum olefin and liquid fuel production. The thermodynamic stability of the various hydrocarbons is reviewed. Under commercial conditions the cracking of a hydrocarbon to smaller molecules is for practical purposes a non-reversible process. However, reactions involving only liberation of hydrogen are of the reversible type. In the paraffins the carbon-hydrogen bond is stronger than the carbon-carbon bond so that the tendency to crack is generally greater than the tendency to dehydrogenate. Processes based on simultaneous cracking and polymerization, on a two-step process involving cracking at atmospheric pressure followed by polymerization at higher pressure, and a two-step process with intermediate hydrogen removal, are discussed. Removal of hydrogen increased the yield of liquid products approximately fourfold. The polymerization of olefins is reviewed. Numerous catalysts have been employed. An advantageous method of operation comprises polymerizing the cracked gas catalytically to convert most of the olefins to polymers and then cracking the residual gas at a temperature higher than the previous cracking temperature to convert the most resistant paraffinic hydrocarbons into olefins. A bibliography of eighty references is appended.

Catalytic Polymerization of Gaseous Olefins by Liquid Phosphoric Acid. I. Propylene. V. N. IPATIEFF. *Ind. Eng. Chem.* **27** (1935) pp. 1067-69.

Liquid phosphoric acid is an effective catalyst for the polymerization of propylene. Its catalytic activity is based upon its ability to form esters

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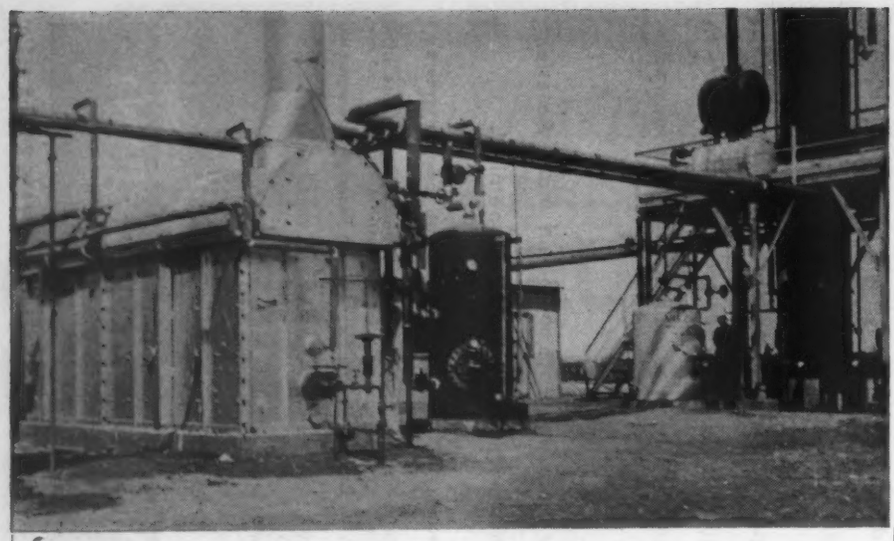

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with the olefins. The ester molecules presumably react with each other to produce polymers, and regenerate phosphoric acid, or to liberate activated olefin molecules which react with molecules of esters or other molecules of olefins to produce polymers and regenerate phosphoric acid. Olefins react with phosphoric acid at relatively low temperatures; for example, 200°C. for ethylene, 125°C. for propylene. Under mild conditions, such as 135 to 200°C., and at 1 to 15 atmospheres pressure, propylene polymerizes to a liquid consisting almost entirely of monoolefins. The liquid polymer distills almost entirely from 40° to 230°C. and is presumably of isostructure. Under more severe conditions the reaction of polymerization is followed by other reactions, and the liquid product contains not only olefins but also naphthenes, aromatics and paraffins. Propylene is polymerized more rapidly by acids that have previously been used for polymerizing butylenes than by fresh acids. Also, the presence of butylene in propylene hastens the polymerization of the propylene.

Catalytic Polymerization of Gaseous Olefins by Liquid Phosphoric Acid. II. Butylenes. V. N. IPATIEFF AND B. B. CORSON. *Ind. Eng. Chem.* **27** (1935) pp. 1069-71.

Butylenes are polymerized by phosphoric acid. The mechanism is assumed to be the same as that for the polymerization of propylene. The speed of polymerization of butylenes is greater than that of propylenes, the rates increasing in the following order: propylene, α-butylene, β-butylene, isobutylene. Gentle polymerizing conditions favor the production of simple polymer mixtures. A mixture of iso- and n-butylenes polymerizes at lower temperature and with lower acid concentration than the n-butylenes alone. The apparatus used is described and tabular data and curves of results are given.

Reaction of Paraffins with Olefins. V. N. IPATIEFF AND A. V. GROSSE. *Jour. Am. Chem. Soc.* **57** (1935) pp. 1616-21.

The authors note that they have found that different classes of hydrocarbons, such as the paraffins, naphthenes, aromatics and olefins, in the presence of specific catalysts, react among themselves with much greater ease than has been sidered possible heretofore. In these reactions metallic halides have proved effective. Practically the only known reaction between hydrocarbons that went smoothly and quantitatively was Balsohn's alkylation of aromatic hydrocarbons with olefins, with aluminum chloride as the catalyst. A number of similar reactions have been studied and will be discussed in a series of papers. The present paper deals with the reaction of paraffins with olefins. A typical example is the reaction of isobutane with ethylene to form the hexane, 2,2-dimethylbutane. All of the paraffins alkylated so far, with the catalyst described, contain a tertiary carbon atom. Attempts to alkylate n-paraffins, as for example n-pentane, with a Boron fluoride catalyst, have not been successful. n-paraffins, with the exception of ethane and methane, can be alkylated in the presence of aluminum, zirconium and other metal halides.

The Polymerization and Hydrogenation of Acetylene. H. A. TAYLOR AND A. VAN HOOK. *J. Phys. Chem.* **39** (1935) pp. 811-19.

When C_2H_2 is polymerized at 495-535°C. the reaction is accompanied by some decomposition, even when a seasoned tube is used. The bimolecular velocity constant at 788°K. is 0.50 litres per mole-second, compared with 1.33 calculated by the collision theory. By the static method with extrapolation to zero time and infinite pressure, E = 40,500 calories.

The Specific Refraction and Other Constants in Connection With the Destruction of Mineral Oils. H. I. WATERMAN. *Jour. Inst. Pet. Tech.*, **21** (1935) pp. 816-24.

The principal purpose of the investigation was to study changes in the cyclic character of an oil at high temperature (435°C.), under high hydrogen pressure (initial pressure 100 kg/cm.^{2}), without a catalyst and in the presence of hydrogenation catalysts such as nickel and molybdenum. It was of particular interest to compare the behavior of an oil rich in aromatic compounds with that of an oil rich in naphthenes. Therefore a Borneo lubricating oil fraction was separated into extract and raffinate by means of liquid sulphur dioxide. The results indicate that the destructive hydrogeneration of the refined product always causes a decrease in molecular weight. The experiments proved that under the given conditions there was practically no

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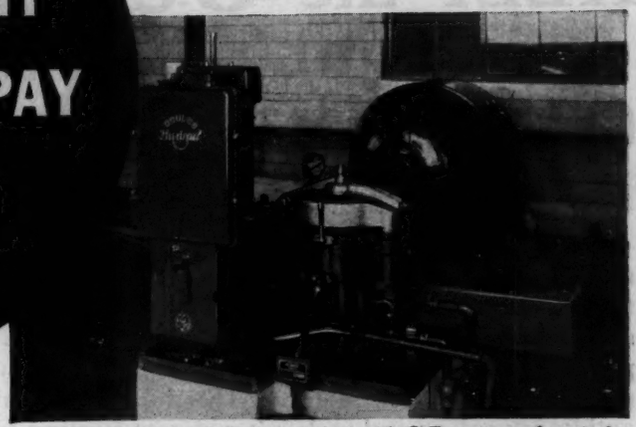
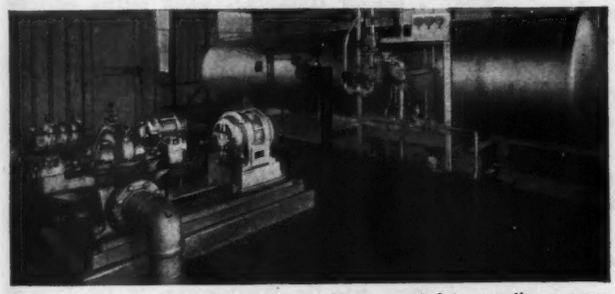
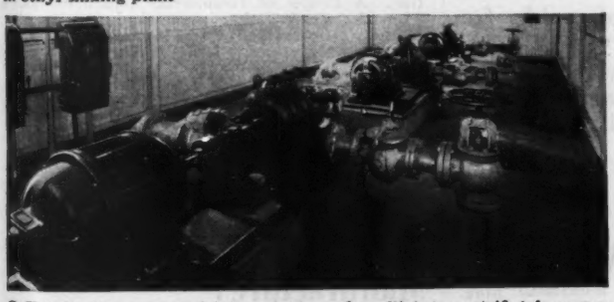


Goulds Hydroil oil reclaimer, equipped with G-E motor and control, at pipe-line station. G-E Type CD direct-current motor, with top-half cover, in the background

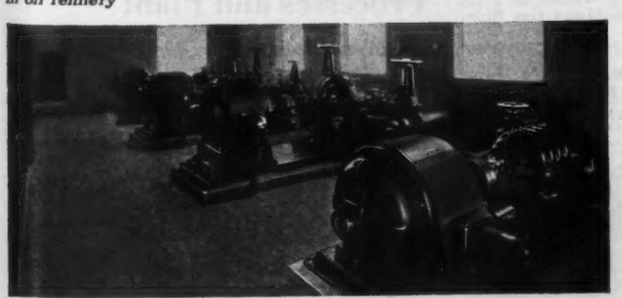
G-E squirrel cage induction motors driving pumps installed in oil refinery



G-E squirrel cage induction motors direct-coupled to gasoline pumps in ethyl-mixing plant



G-E induction motors driving single and multistage centrifugal pumps in oil refinery



G-E induction motors direct-coupled to multistage centrifugal pumps

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The illustrations show important installations which are completely G-E driven and controlled.

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WHEN gasoline is withdrawn from a tank it oftentimes has very different properties than it had when it was put in storage. Careful checks have repeatedly shown that gasoline stored in an ordinary cone roof tank loses approximately one pound per square inch of vapor pressure every three months. This loss reduces the anti-knock rating and makes it a slower starting fuel.

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80,000-barrel Hortonspheroid at South Portland, Me. Storing motor fuel at 1½ lbs. pressure.

change in the total amount of rings in the product. Only in the case of the use of nickel as catalyst is there a small loss in number of rings. The results for the refined product and also for the extract indicate a regular destruction of molecules in which the molecules have been split into analogous parts. This may be considered a depolymerizing action.

Organic Reactions With Boron Fluoride. X. Condensation of Propylene With Aromatic Hydrocarbons. S. J. SLANINA, F. J. SOWA AND J. A. NIEUWLAND. *Jour. Am. Chem. Soc.* **57** (1935) pp. 1547-49.

Boron fluoride has been shown to function favorably as a catalytic agent in the condensation of olefins with phenols and acids. In this previous work by the author and his associates it was noted that whenever benzene was used as a solvent in condensations with propylene, appreciable quantities of a product boiling around 152°C. was isolated. This product proved to be cumene, and its presence could be accounted for by considering the overall reaction as a direct condensation of propylene with benzene, catalyzed by boron fluoride. A study of this reaction and similar reactions was therefore made, a report on which is given in the present paper. Mono-, di-, tri-, and tetraisopropyl derivatives of benzene have been prepared by the condensation of propylene with benzene. Acidity has a great influence on the rate of condensation and is directly proportional to the acidity of the catalyst carrier. Aluminum chloride promotes the formation of m-diisopropylbenzene, whereas boron fluoride gives p-diisopropylbenzene.

The Reaction Between Sulfur Dioxide and Olefins. II. Propylene. M. HUNT AND C. S. MARVEL. *Jour. Am. Chem. Soc.* **57** (1935) pp. 1691-96.

Sulfur dioxide and propylene combine to give a product $(C_3H_6SO_2)_n$ which differs markedly in physical and chemical properties from the polysulfone which has been obtained from cyclohexene and sulfur dioxide. The propylene derivative is unusual in that it is insoluble in all organic solvents and is soluble in dilute aqueous alkalies; but is easily decomposed by the alkalies to yield fairly simple products. The experimental work is described and the reactions of the various products discussed.

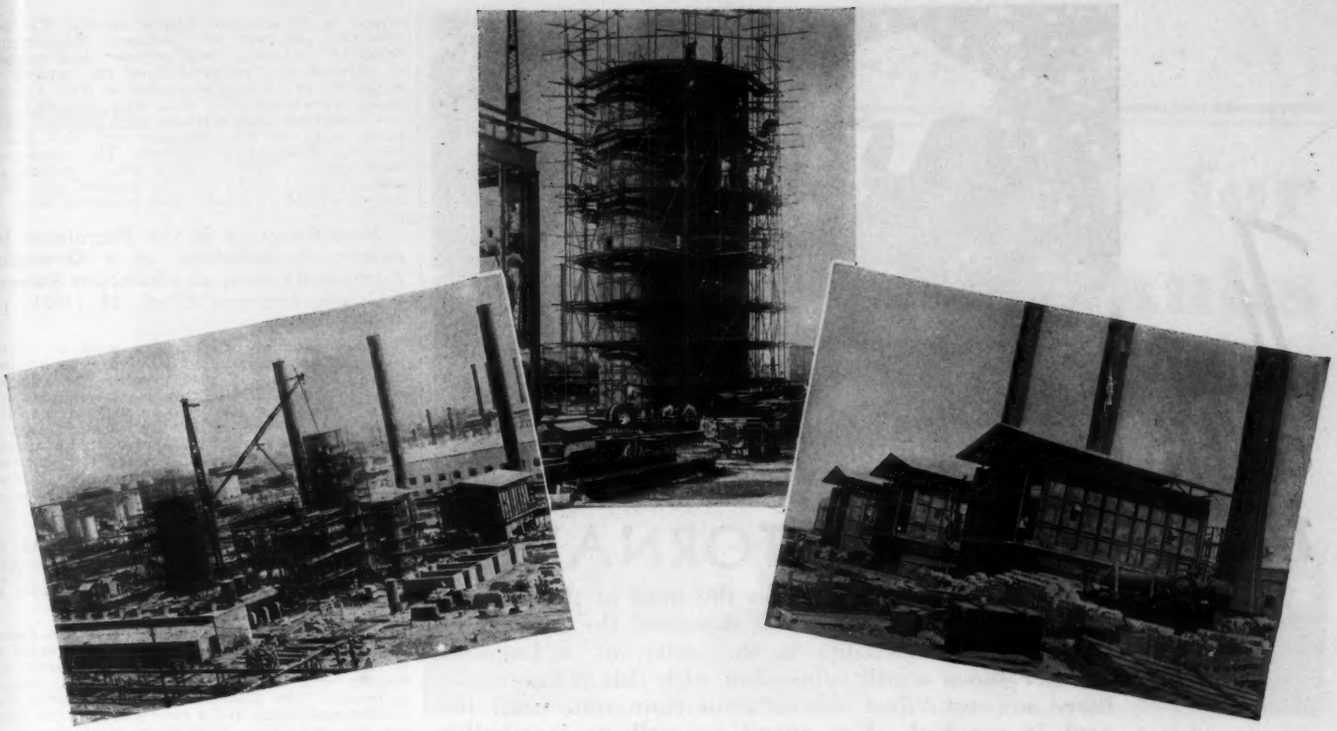
Acidic Constituents of a West Texas Pressure Distillate. M. WILLIAMS AND G. H. RICHTER. *Jour. Am. Chem. Soc.* **57** (1935) pp. 1686-88.

The object of the work described in this paper was the determination of the type of acids present in a Texas naphthenic acid fraction. A sample of commercial naphthenic acids from the alkali wash of a cracked pressure distillate was furnished by a local refinery. The charge to the cracking still was the gas oil fraction of a West Texas crude. The experimental work done is described. Commercial naphthenic acids from this pressure distillate were shown to consist in large part of phenolic components. Among the compounds isolated and identified were: ethyl mercaptan, phenol, o-cresol, m-cresol, p-cresol, 1,3,5-xylenol, 1,4,2-xylenol, isovaleric acid n-heptylic acid, n-octylic acid and n-nonylic acid. These results do not agree with those of earlier investigators who reported the finding of the cyclic compounds exclusively.

Manufacture: Processes and Plant

Polymerization, a New Source of Gasoline. V. N. IPATIEFF, B. B. CORSON AND G. EGLOFF. *Ind. Eng. Chem.* **27** (1935) pp. 1077-81.

The catalytic process of the Universal Oil Products Company for the production of gasoline from olefins in cracked gas is described. A plant capable of processing 3 million cubic feet of gas per day has been built, and at the time of writing the article had been operated continuously for twenty-three days producing 313,000 gallons of 81-octane gasoline from 58,000,000 cubic feet of gas, the propylene-butylene content of which was 27.4 percent. The potential production of polymer gasoline from the refinery gas of the country is approximately 1 billion gallons per year. The total gasoline production of the country is slightly less than 18 billion gallons. The catalyst used in this process operates under mild conditions, such as 446°F. and 200 pounds pressure. It is a granular solid that is not poisoned by carbon monoxide, hydrogen sulfide, mercaptans, or other components of refinery gases. However, the catalyst loses its activity with continued use, but can be regen-



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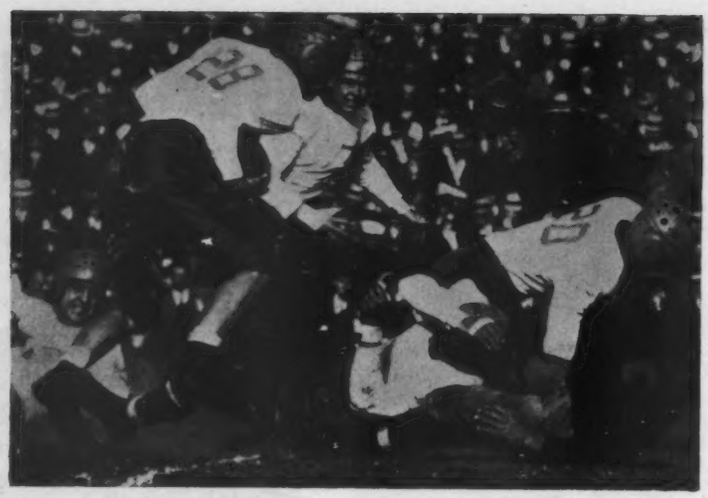

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erated to its original activity so that the time efficiency is over 90 percent. Regeneration comprises removing high-polymer hydrocarbons or carbonaceous material from the catalyst by air oxidation. It is accomplished in situ. Cracked gases containing 17.6, 37.5, 43.1 and 69.7 percent propylene and butylene gave gasoline yields respectively of 3.3, 6.0, 6.8 and 10.9 gallons per one thousand cubic feet. The commercial plant gives a yield of more than 5 gallons per one thousand cubic feet of cracked gas. Data are presented in tabular and graphical form.

New Reagents in the Petroleum Industry. Naphthalene as a Dewaxing Agent and Cresol as a Selective Solvent. E. KATZ. *Przemyst Chem.* **18** (1934) pp. 408-19.

Wax containing oil diluted with a solvent naphtha was treated by dissolving naphthalene therein and cooling to crystallize the naphthalene to yield a filterable mass retaining the wax. Cresol was also used in place of naphtha. Upon cooling two layers are formed: Wax is present in the upper layer only. In an alternative procedure, alcohol was added to the cresol-petroleum oil solution, whereupon the fractions separated in the order of their solubility in cresol.

Refining of Paraffin by Means of Ferric Sulfate. Z. Z. BILUCHOWSKI AND R. DOBROWOLSKI. *Przemyst Chem.* **18** (1934) pp. 309-13.

Paraffin of 50-52°C. boiling point was heated at 135-8°C. with ferric sulfate for a period of three hours. The oil was then filtered and treated with diatomaceous earth and sodium carbonate. The process was then repeated with smaller quantities, and a colorless, odorless product obtained. This method of treatment, it is claimed, presents many advantages over the usual treatment with sulphuric acid.

Steel Embrittlement. H. VOLLBRECHT AND E. DITTRICH. *Chem. Fabr.* (1935) p. 193.

The embrittlement of steels at high pressure and temperature through the action of hydrogen and hydrogen sulphide was studied with the result that it was concluded that hydrogen corrosion is more serious than that caused by hydrogen sulphide. Apparently the sulphides formed effect protection against attack by hydrogen.

Products: Properties and Utilization

The Vapor Pressures of Liquid Fuels. J. VERDIER AND L. HUREL. *J. Usines Gaz* **59** (1935) pp. 35-41.

Vapor pressures were determined in an apparatus similar to the A.S.T.M. apparatus at air to liquid ratios from 10 to 10,000, and temperatures from 16° to 0°C. The volume of liquid used in these experiments was varied; curves are given for vapor pressure vs. volume of liquid. When pure substances are used these curves are constant as soon as the gas is saturated with vapor. When fuel mixtures are used the constant values of vapor pressure are not obtained unless large amounts of liquid are used. Gasoline-alcohol mixtures have lower vapor pressures at high concentration, and higher vapor pressures at low vapor concentration than gasoline. This is also true of gasoline-benzene mixtures. Studies were made of various ternary solutions of gasoline, alcohol and benzene. The conclusion was reached that for ease of starting ternary mixtures are favorable.

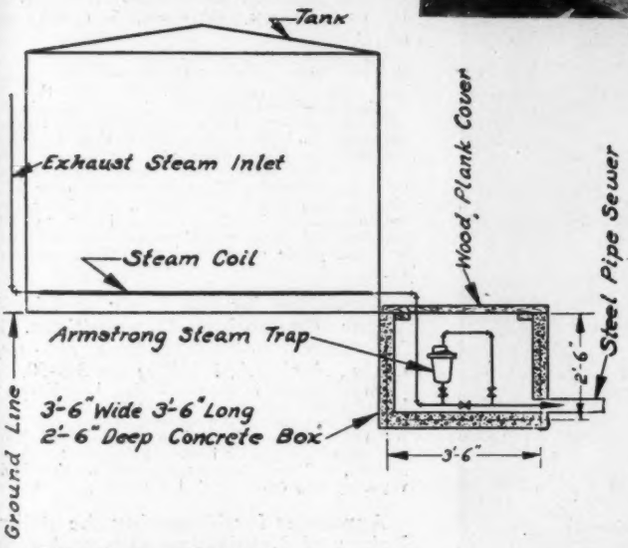
Ethyl. F. R. BANKS. *J. Roy. Aeronaut Soc.* **38** (1934) pp. 309-72.

The author concludes that supremacy in the air will be had by the nation that develops engines that use high anti-knock fuels to the fullest extent. $PbEt_4$ is an essential component of such fuels. When using mixtures high in benzene the temperature of the cylinder head and the exhaust gas rises, but this does not occur with ethylized gasolines. Airplane-engine development is discussed at length, as well as the effect of leaded fuels.

Rapid Determination of Gum in Gasoline. P. WOOG, J. GIVANDON AND A. CHMELEWSKY. *Rev. Petrolifere* **635** (1935) p. 757.

A method for the determination of gum in gasoline that has been previously described was simplified so that routine tests can be completed in one and one-quarter hours. The method

Heating Coils for Oil Storage Tanks need *dependable* ARMSTRONG TRAPS



This diagram shows a typical hook-up for a heating coil in an oil storage tank.

WHEN low temperatures make heating coils in oil storage tanks necessary, an air or water bound coil can cause no little trouble and delay in refinery operations.

Because most of these oil tanks are heated with exhaust steam at comparatively low pressures it is doubly important that efficient steam traps be installed on the coils. The low pressure will not force the condensate through a sluggish, dirt-clogged trap.

For this reason, refineries are demanding that oil tank heating coils be equipped with dependable Armstrong Traps. All condensate and air are quickly and thoroughly drained as soon as steam pressure comes on. The advantages of Armstrong Inverted Bucket Traps, their reliability under all service conditions—large capacity and self-scrubbing features that keep them clean at all times, all recommend them especially for this purpose.

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comprises the separation of the gum, and the titration. 100 cc. of the sample is distilled in an Engler flask on an oil bath at 160°C., first at ordinary pressure for fifteen minutes, and then under vacuum. Total time for distillation and for drying under vacuum is forty minutes. Gum is dissolved in 15 cc. CCl_4 and titrated with KI solution and N-thiosulphate after the addition of sulphuric acid and potassium permanganate. The method can also be applied to the accelerated aging test.

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Artificial Ageing of Lubricating Oils. S. FACHINI AND F. SPORER. *Petr. Zeit.* **31** (1935) p. 23; *Motorenbetrieb* **8** (1935) p. 4.

Sludge formations from lubricating oils is discussed. It is attributable to oxidation, condensation and polymerization under the influence of heat, air, and time. Oils were aged in the laboratory by heating in a standard porcelain dish at atmospheric pressure and at 150°C. for 15 hours or more. After the heating the oil was cooled and dissolved in petroleum ether and the insoluble residue filtered and weighed. The point at which sludge first separates is characteristic of the oil and varies from 15 to 150 hours. Oils are classified into four groups in accordance with the time required for sludge formation and the nature of the process of sludge formation.

Pitch Coke and Petroleum Coke. ANON. *Engineering,* **139** (1935) pp. 585-6.

Petroleum cokes are of two types, the older being from coking stills and the newer from cracking operations. The former is a hard brittle material with a carbon content corresponding to $C_{100}H_6$. This coke is one of the purest industrial forms of carbon. The ash content is low. Cracking still coke is now of greater importance. Its composition varies with that of the oil used from 94.6 to 87.15% fixed carbon, 0.36 to 4.18% sulphur, and 3.75 to 12.28% volatile matter, when made from Kentucky and Arkansas fuel oils respectively. The coke is always of a honeycomb structure and is brittle. In Germany pitch coke is preferred by electrode manufacturers because of its uniform quality. It is made by the coking of coal-tar pitch in cast-iron retorts.

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The Effect of Heavy Oils and Greases on the Fatigue Strength of Steel Wire. R. GOODACRE. *Engineering* **139** (1935) pp. 457-58.

The Haigh-Robinson fatigue-testing machine was used to examine twelve oils, all containing a bitumen base. Four also contained fillers, two of which were fibrous. Oils and greases increased the limiting fatigue strength of the wire, presumably by excluding oxygen, which is known to have an important effect in corrosion fatigue. Small surface imperfections are filled, thereby avoiding concentration of stress. The more viscous the oil, the more are fatigue properties improved until a limiting viscosity is reached. Maximum fatigue strength is greater with oils containing fillers, and occurs at higher viscosity. When polished wires were used the effect of viscosity was less, and fillers had no effect. At stresses higher than the limiting fatigue strength, oils were beneficial both on polished wire and wire as drawn.

Protective Action of Bituminous Paints Against Corrosive Liquids. C. R. PLATZMANN. *Bitumen,* **5** (1935) pp. 61-62.

Quality of bituminous paints depends upon the properties of the bitumen and the amount and nature of the solvent. The fact that the finished coating has a high gloss is no criterion of high quality. High melting point bitumen prepared by high vacuum distillation, is not as valuable for the making of paint as the blown bitumen. The thinner used should be free from acids and phenols. Tests were made over a period of two and a half years, and bituminous coatings were found to be resistant to 10% solutions of sodium and magnesium sulphates, but susceptible to the action of dilute sulphuric acid.

Apparatus for the Study of Liquid-Vapor Equilibrium Compositions. R. M. WILEY AND E. H. HARDER. *Ind. Eng. Chem., Anal. Ed.,* **7** (1935) pp. 349-50.

An apparatus is described that is believed to have considerable advantage in speed, simplicity, and convenience over devices previously used for the purpose of obtaining samples of liquid and vapor in equilibrium. The apparatus is described, and a typical set of data for the liquid-vapor system ethyl alcohol-water is presented.

Apparatus for Measuring the Boiling Points of Lubricating Oils and other Compounds of High Molecular Weight at Reduced Pressures. S. T. SCHICKTANZ. *J. Research Natl. Bur. Standards* **14** (1935) pp. 685-92.

For the accurate determination of boiling points of lubricating oils and other compounds of high molecular weight, the author uses an apparatus in which three thermocouples are positioned at different heights in the vapor column. If the substance is pure, the couples give identical readings, and if impure the differences in the readings are an indication of the purity. Data are given for such substances as di-Buphthalate, and for mixtures of this with tri-o-tolyl phosphate, and also for 2 lubricating-oil fractions as secured from successive distillations.

A Rapid Precision Viscometer. O. FITZSIMONS. *Ind. Eng. Chem., Anal. Ed.,* **7** (1935) pp. 345-7.

The accuracy of the Saybolt viscometer is compared theoretically with viscometers the efflux time of which is linear with viscosity. The possible errors resulting from the use of data taken with the Saybolt instrument in determining the viscosity index of light oils are discussed. The Ubbelohde capillary viscometer has been modified by the use of duel capillaries and by mounting the whole assembly in a vapor bath. Data can be more rapidly secured than by means of the Saybolt instrument, and the procedure has the accuracy inherent in capillary viscometers. The degree of accuracy is at present limited by the viscosity standards available. Checks on the same instrument to better than 0.1 percent are attainable. The instrument requires a small sample, 12 cc. being sufficient for a determination.

New Equipment for the Modern Plant

Hatch Latch

ENARDO MANUFACTURING COMPANY

Enardo Manufacturing Company, Tulsa, has announced a "step-on" spring bail which serves as an automatic latch in connection with the full line of thief-hatches made by the company. Hatches are furnished with or without bail. Eight models of hatches are offered in all-aluminum and eight in gray iron. The models include a round hatch and a long hatch, both made in the two-inch base and the 10-inch base, and both with and without the automatic latch "step-on" spring bail.

A felt backed, gasoline and oil proof cork fibre gasket is used on all models and is so arranged that ice and dirt will not gather on it, thus preventing its proper function. The eight all-aluminum models will not spark when struck by metal and form a safety precaution against the hazard of fire. Also the tall 10-inch model eliminates the necessity of installing an iron collar on water-seal tanks.

The thief-hatch opening on the round model is eight inches in diameter and the long model is 7¾ by 17½ inches. Special interest has been manifested in the models with the "step-on" spring bail, the manufacturer claims. It eliminates much of the danger of getting the head too close to the opening and breathing fumes from the tank. When the lid is flipped over it latches in an automatic fashion. It may also be opened by the foot.

Pre-Coat Filter

OLIVER UNITED FILTERS, INC.

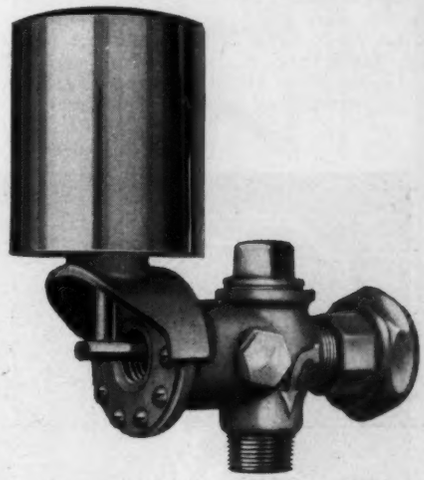
Oliver United Filters, Inc., 33 West Forty-Second Street, New York, has perfected and placed on the market a new pre-coat filter with special application to refinery work.

Clarification of fuel oils and continuous contact filtration is effected by the Oliver pre-coat filter. This operation is said to be unique in that a totally clean filter surface is exposed with each revolution of the drum. This drum is coated with a heavy homogeneous layer of filter aid and rotates in the material to be clarified. Vacuum applies as on the standard Oliver, causes the liquor to be drawn through the heavy layer of filter aid, the solids being deposited on the outer surface. This deposit together with a very thin layer of filter aid is continually removed by a special mechanism, thus presenting a fresh surface for rapid filtration. High rates are maintained over long periods and in addition emulsions can be broken and remarkable separation of colloids secured, the manufacturers state.

Control Valves

LAMMERT & MANN COMPANY

Lammert & Mann Company, 264 N. Wood Street, Chicago, announces a line of control or automatic shut-off



Lammert & Mann Control Valve

valves, which are made in standard sizes from ⅜ inch up. The control or automatic shut-off valve is said to embody new features and refinements such as few parts, compactness, large capacity, simple design and construc-

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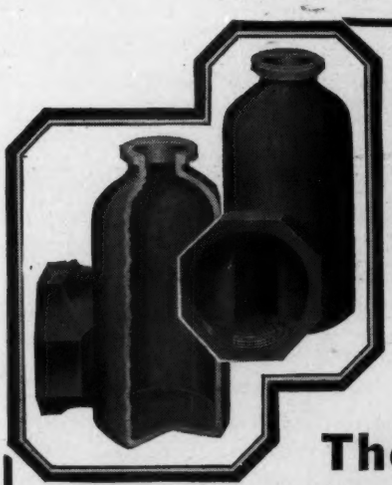

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tion, interchangeable elements for air control, steam pressure control, water pressure control or electrical control. Any of these controls is connected by merely screwing it into the standard valve-body mechanism. The valves can be adopted to automatic operation, to remote control or to automatic operation plus an interlock with a manual reset device.

The valve itself has but two moving parts and is held firmly in position, when closed, by a cadmium-plated spring. The valve needle and seat are of stainless steel, insuring perfect seating, quick action, trouble-free service and long life. All other parts are also of non-corrosive metals. Unusual ease of dis-assembly is a feature. Any part of the valve can be removed in a few seconds, without detaching the valve from the line.

The operating lever, which is actuated by the control device, transmits the force to lift the needle valve. A packless gland in the form of a brass bellows is used, giving a perfect seal.

The air-control mechanism is of the piston type, and a pressure of 3 to 50 pounds may be used. All parts of the air-control are free-moving, free from binding or sticking. The air-operated valve is used on oil burners of the air-atomizing type. It prevents oil dripping into the combustion chamber when the burner is off, and closes the valve automatically in the absence of the atomizing agent.

In the steam or hydraulic control, the pressure operates through a bellows. No stuffing boxes or packed joints are used. The steam-oil and air-oil interlocks are used on industrial oil burners where the atomizing agent, either steam or air, and the oil are supplied by separate units. If the steam or air fails, the oil supply is immediately shut off, locked shut, and cannot be started until released by hand.

The electrical control of the Lammert valve is through an electro magnet, and the spring which closes the valve is entirely separated from the fluid. It is fully enclosed, but easily accessible upon removing the metal cup cover. The electrically-operated valve is used for remote control of any liquid—oil, water, brine, etc. The gravity closing action of the valve is made more positive by a stout spring.

Angle Switch

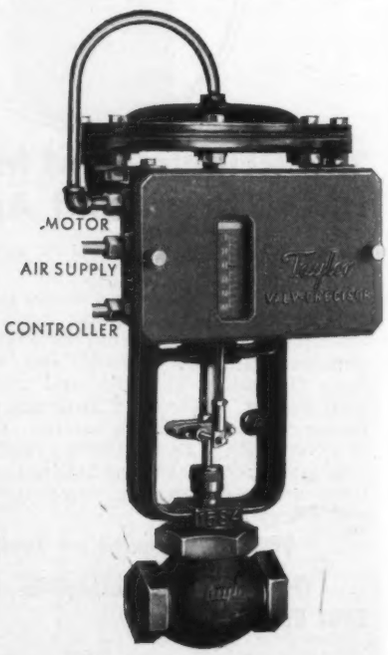
WESTINGHOUSE ELECTRIC & MANUFACTURING COMPANY

Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., announces development of new angle switch equipment for controlling large synchronous motor-driven reciprocating pumps and compressors to prevent the compression strokes on different units occurring in unison. Employing an electronic tube, the device effectively reduces the magnitude of current pulsations where two or more drives are used. Minimum pulsations are desirable to reduce flicker in lights and interference with the operation of other electrical equipment.

Valve Control

TAYLOR INSTRUMENT COMPANIES

Taylor Instrument Companies, Rochester, New York, has announced a new type valve control that is the "Valv-Precisor." The new arrangement was designed to meet the demand for closer control of processing and to overcome hysteresis



Taylor Valve Control

THE BANKER
Of prime importance in commercial life since the adoption of the monetary medium of exchange.

Were The Banker to serve only as a storehouse for money, his value to his community would be small. The maintenance of strong vaults is only incidental to the service he renders his customers beyond the protection of their money.

So, too, in our industry. Refineries using our fittings are getting the finest that experienced designers and skilled workmen can produce from good materials. But they are getting only a part of the service we can offer.

Key Re-conditioning Service is the final link in the chain of services which we can offer. Years of tests and experimental work have resulted in the development of re-conditioning tools and methods that extend the life of return bend fittings from twenty to one hundred percent.

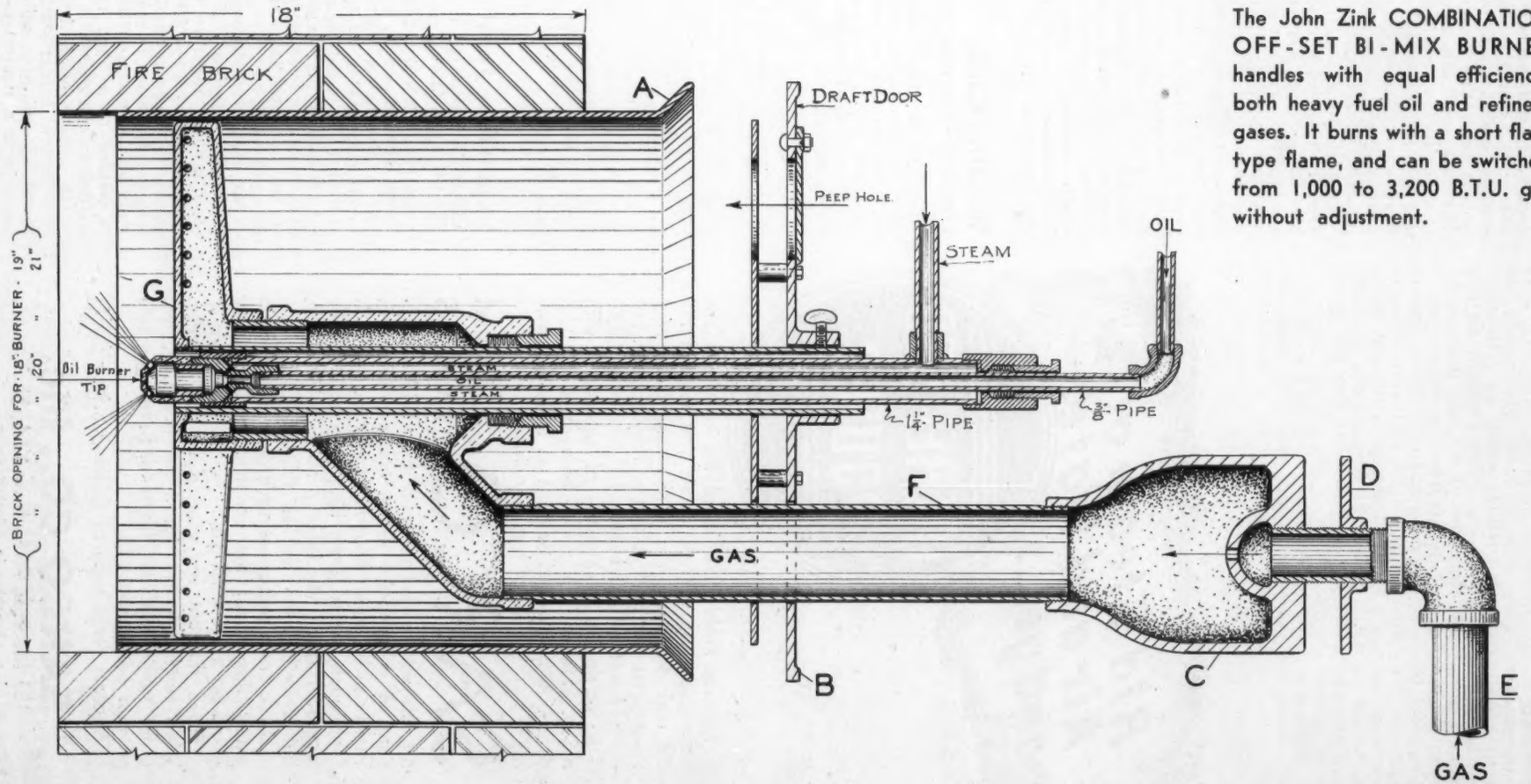
Key Re-conditioning Service is generally performed in the refinery yard. In all cases the work is only entrusted to mechanics who have served a long apprenticeship in our organization and who have specialized in this type of work.

"Service after the Sale" is the phrase we use to describe this service. We consider it as important to the refinery as the originality of our fittings. Key Refinery Fittings are in service all over the world and Key Re-conditioning Service is available to refiners everywhere. The contract rate will be quoted on request.

KEY COMPANY

EAST SAINT LOUIS, ILLINOIS
NEW YORK CITY TOLEDO TULSA DALLAS HOUSTON
LOS ANGELES SAN FRANCISCO

Short Flame REFINERY BURNER



The John Zink COMBINATION OFF-SET BI-MIX BURNER handles with equal efficiency, both heavy fuel oil and refinery gases. It burns with a short flare type flame, and can be switched from 1,000 to 3,200 B.T.U. gas without adjustment.

There is a John Zink burner for every refinery or industrial use . . . Bi-Mix Short Flame Gas Burners, Combination Gas and Oil Burners, Low Pressure Heating Burners, Domestic Burners, Acid Sludge Burners, Round Flame Outside Mix Steam Atomizing Oil Burners, Round Flame Inside Mix Steam Atomizing Oil Burners . . . STRAIGHTENING VANES—Reid Screen Type, Tubular Type, Cast Iron Wing Type.

Low first cost and inexpensive installation are characteristic.

Write, wire, or phone for complete details.

JOHN ZINK BURNERS

TULSA, OKLAHOMA

(friction and lost motion) of diaphragm motors. Heretofore the manufacturer claims that only specialized instruments could maintain precision control under severe conditions. The precision-valve-action feature has proved so important that the company has made the feature available in a separate instrument for those applications where load changes are not a problem, but where valve-stem friction and diaphragm-motor hysteresis must be overcome to obtain precision control. The manufacturer claims that in general any air operated controller with the aid of the "Valv-Precisor" can position the valve 50 times more accurately when opposed by valve-action friction and diaphragm-motor hysteresis than when the device is not used.

Coatings

TECHNICAL COATINGS, INC.

Technical Coatings, Inc., 11 Park Place, New York, has introduced a line of new coatings which are asserted to be unlike any other available, in that the films formed are free from porosity and impervious to water and corrosive atmospheric gases. These finishes are the result of prolonged research at a leading technical institute in which, it is stated, the first vehicle, or "base" to form an impervious film was developed.

This vehicle is described as a combination of pure vegetable gums and heat-treated oils made in an original and unique manner. It contains no linseed oil or synthetic resins. It forms films which are air-tight and water-tight, which are elastic and which produce hard films that will not peel, chip, nor crack. For this reason they assertedly rank high in protective value and in preventing corrosion of metals. They are applicable also to wood and to other surfaces such as dry concrete and plaster. Resistance to salt and fresh water and to all degrees of humidity as well as to extremes of temperature is unusual.

Primers with the new non-porous base are available for various purposes. Metallic zinc is especially good on black and galvanized surfaces and where salt-water exposure is severe. A combination of zinc and aluminum is recommended for fresh-water and humid conditions or where condensation occurs. A balanced red-lead, which is held in suspension permanently, is used as a primer for average conditions. Finishing coats in standard colors are also available, as is a high-gloss, acid-resistant grey. A vehicle for aluminum which requires 25 percent less aluminum powder than other vehicles, is also employed for finishing coats.

Welding Cable

LINCOLN ELECTRIC COMPANY

Lincoln Electric Company, Cleveland, Ohio, has announced a new type of welding cable designed to meet conditions of extremely severe wear and abrasion.

This new cable consists of fine tinned copper wire laid in ropes and stranded. Individual ropes are alternated in succession as regards the direction of the lay to prevent distortion in applications of severe usage. The conductor of "Realwear" cable is insulated with an especially developed rubber compound to provide firm adhesion between the cover and rubber insulation. High grade cotton woven on a loom and securely joined to the rubber belt by a special process forms the cover. The cover is provided with a finish very resistant to oil, grease, acid, gasoline, moisture and heat. The strength of the new cable is comparable to that of fire hose.

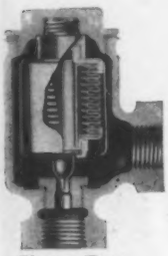
Expansion Joint

AMERICAN DISTRICT STEAM COMPANY

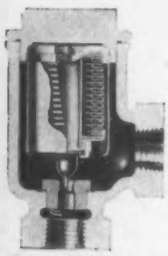
American District Steam Company, North Tonawanda, N. Y., has patented and is placing on the market a new packless expansion joint, known as the U-Ring type, based on a new principle for controlling pipe expansion in steam and hot water lines, or pipe lines conveying gases or fluids subject to temperature variations.

The expansion element is a series of die-formed "U-rings" of stainless alloy steel, welded together without transverse seams by a special process which retains the basic strength of the metal. One end is welded to the wrought steel body of the joint and the opposite end is welded to a plate that is in turn welded to the sleeve.

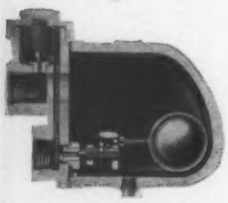
The joint is installed with the expansion element compressed so that under actual operating conditions, the element is in a neutral or normal position, free from flexing strain when under maximum line pressure. Control rings and stop-bolts distribute the ex-



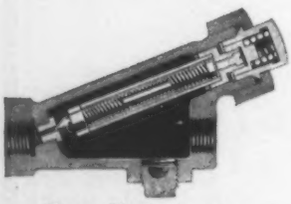
Steam Trap
No. 9-2
Pressures 0 to
125 lbs.



Steam Trap
No. 9-200
Pressures 0
to 200 lbs.



Float and
Thermostatic
Trap
Pressures
0 to 200 lbs.



Steam Trap
No. 8
Pressures
50 to 300 lbs.

You can't obtain efficient use of steam nor economical use of fuel, unless you remove the air and discharge the condensate from your steam lines and coils as fast as they appear. For air and water fight heat.

By equipping each piece of equipment with a Sarco Steam Trap, air will be vented and condensation discharged as soon as formed, assuring a steady flow of hot, dry steam.

SARCO STEAM TRAPS

are inexpensive enough to justify individual trapping at every point where condensate forms. There can be no air bound or water logged coils —no heat wasted from long lines to centrally located traps. They take up no valuable space, but screw into the line like a fitting.

Sarco Traps are effecting large fuel savings in plants throughout the country. Perhaps they would do likewise for you.

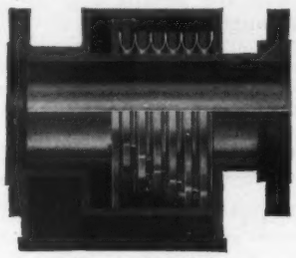
Prove this out for yourself at our expense. We'll send one free for a month's trial. No proof, no charge. But thousands have been sold on that test alone.

Also ask for a copy of Catalog S-95.

SARCO CO., Inc.
183 Madison Ave., New York, N. Y.
Branches in Principal Cities
SARCO CANADA LIMITED
Federal Building, Toronto, Ontario, Canada

pansion and contraction movement equally through the U-rings.

The expansion joint is fully guided at three points to permit the sleeve to move freely without binding. It is made with a wrought steel body which fully encloses the expansion element and protects it from damage or dirt. The joint is available for pressures to



Expansion Joint

400 pounds and temperatures to 800° F., with flanged ends or beveled ends for welding directly into the pipe line; with or without anchor base.

Any reasonable amount of traverse can be provided, with a normal range of one inch to eight inches. The full amount of traverse is available as the element is under least flexing strain when the sleeve reaches its rated traverse. It does not require service or maintenance and is especially desirable for underground pipe lines, power house piping or inaccessible locations where space is limited.

Cylinder Manifold

THE LINDE AIR PRODUCTS COMPANY

The Linde Air Products Company, New York City, has announced a new wall type acetylene cylinder manifold, the Oxweld Type M-8. It is available in a 10-cylinder unit to which extensions in units of five cylinders or 10 cylinders can be made. The new manifold has been accepted by Underwriters' Laboratories for listing under their re-examination service. The manifold consists of two high-pressure header units. These feed into a central regulation system which delivers acetylene to the distribution piping system at pressures up to 15 pounds per square inch.

The header unit assemblies are composed of heavy seamless steel tubing with forged steel union connections having stainless steel seat inserts. Header valves for cylinder connections are of heavy construction and are threaded directly into the steel tubing header. The extreme ends of the header assembly are closed with forged steel caps. Connections from the header valves to the cylinder valves are made with flexible leads. Each is coiled to provide sufficient flexibility, fitted with an approved Prest-O-Lite flash arrester and is provided with a ball check valve in the header end. This guards against the possibility of acetylene from the header being driven back into an exhausted cylinder.

The two high-pressure header assemblies are connected by forged steel unions to a central system of six valves and two regulators for controlling the operation of the manifold. These regulators have been designed for heavy-duty service, and will handle a wide variation in load with less effect on the delivery pressure than would ordinarily be expected.

Centrifugal Pump

LAWRENCE PUMP & ENGINE COMPANY

Lawrence Pump & Engine Company, Lawrence, Mass., announces a new, compact, low cost, centrifugal pumping unit for small and moderate capacities, under the trade mark "Electropump."

The Electropump is directly coupled to drip-proof, ball-bearing electric motors. The impeller is of the enclosed type and is mounted, keyed and locked on the extension of the motor shaft. The pump is for operation against heads up to 150 feet or 65 pounds in a single-stage unit and twice the head or pressure when furnished in a two-stage unit.

The unit is fitted for circulating hot and cold water or brine, for water supply systems and booster service, low pressure boiler feeding, condensate returns, air conditioning apparatus, transfer of oil and other liquids.

In this compact pump, the ball bearing motor and pump are built into one unit and the number of rotating parts are kept down to a minimum. This type of construction makes a self-contained, light-weight, easily portable unit that can be operated equally well in vertical, horizontal or inclined positions.

All units are thoroughly tested under conditions similar to those found in the field and the given efficiency ratings are most conservative. Complete performance curves and data on any size pump will be furnished by the Engineering Department of Lawrence Pump & Engine Company.

E V

HIGH PRESSURE

DROP FORGED STEEL VALVES

GLOBE
ANGLE
BALL CHECK
NEEDLE
METER

Valves trimmed with "EValloy" Stainless Steel

In sizes 1/8" through 2"

Figure 2688

•

Suitable for a range of working pressures from 600 to 6000 pounds.

Section "G" of Catalog No. 11, just out, covers complete details.

•

Large Stocks Carried in our Houston Warehouse

•

MAINTENANCE ENGINEERING CORP.

1400 Conti Ph. P-6338 L.D. 409

HOUSTON, TEXAS

$31,400 saving in reclaiming valves

That is what one oil company figured Oakite cleaning was saving annually by re-claiming valves alone,—not to mention pipe fittings, gauges, regulators, and blow-off cocks that are handled in the same two Oakite tanks.

When you note that the ENTIRE cost of operating the salvage department was only $5,000, you will agree that here is an economy which no company can fail to investigate. Efficient cleaning is the first step in reclaiming good dollars from old equipment, in preparing used parts so they WILL BE re-used. Write for free cleaning data.

Manufactured only by

OAKITE PRODUCTS, INC.

50B Thames Street, New York, N. Y.

Branch Offices and Representatives in all Principal Cities of the U. S.

Since 1909 the Standard of Cleaning Quality

OAKITE

Industrial Cleaning Materials and Methods

POLYMERIZATION Points The Way To GREATER EFFICIENCY AND SO DOES

SAND BANUM

"The Entirely Different Boiler and Engine Treatment"

Sand-Banum means a more efficient and more economical power plant. Sand-Banum cuts operating costs of boiler and water cooling systems like Polymerization "changes molecules." And what a "rating"—scale and corrosion cannot form in the presence of Sand-Banum!

Furthermore, Sand-Banum brings you a SIMPLICITY and CERTAINTY you may have heretofore regarded as "impossible."

Send for booklet "HOW and WHY" explaining this modern, pure colloidal treatment.

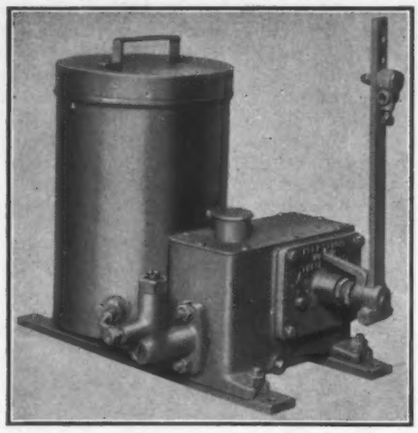
American Sand-Banum Company, Inc.
342 Madison Ave., New York City

Stocks carried by
WESTERN SAND-BANUM COMPANY
Houston, Texas Denver, Colo.
Fresno, Calif.
and at other convenient points.

Chemical Measuring Pump

THE McCORD RADIATOR & MFG. CO.

The McCord Radiator & Manufacturing Company, Detroit, Mich., has developed a measuring pump for metering quantities of chemicals or other liquids. The new



McCord Chemical Measuring Pump

measuring device will deliver a predetermined amount of liquid, proportioned according to requirements, over a definite period; or a measured quantity, according to the speed of the operating machine. The design insures positive delivery of liquids against pressures up to 2000 pounds, the manufacturer claims. The pump is especially suited for use in injecting treating chemicals.

Brake Lining

THERMOID RUBBER COMPANY

Thermoid Rubber Company, Trenton, New Jersey, has announced the perfection of a new type of brake lining, called Thermoid BX Woven, for use on heavy industrial machinery and equipment. This brake lining has as its base asbestos tape that is woven in a single thickness and therefore has no plies to separate under severe service conditions. This tape is woven of heavy yarn containing brass wire and is impregnated with a highly heat-resistant bakelite resin. The resultant product is a dense, flexible material consisting of 70 percent asbestos and 30 percent resin. It is ground on the wearing surface, ready for application.

Thermoid BX Woven Brake Lining has a very high coefficient of friction under all conditions of service; gives quick deceleration and "high holding," the manufacturer claims. It will stand heats above 900° F. without deteriorating; and it is claimed there is no material decrease in efficiency in the presence of oil, grease or water.

Pumps

WORTHINGTON PUMP & MACHINERY CORPORATION

Worthington Pump & Machinery Corporation, Harrison, N. J., announces that its open impeller non-clogging centrifugal pumps for handling solid materials in suspension, gritty liquids, liquids containing stringy material, etc., now are being made in a wide range of sizes. The pumps are of rigid "Monobloc" construction, and are low in first cost. They are compact, the greatest overall length of the largest size being only 23 inches.

The shaft of large size, extra-heavy-duty grease-lubricated ball bearings, rugged casings, stuffing box of ample depth arranged for water or independent seal, water thrower ring, splash-proof motor, fan for air circulation, and protecting apron on motor—are some of the details that characterize these units.

They are available in all-iron, all bronze, or bronze-fitted, and for special services as in chemical plants, refineries. Such special materials as stainless steel, Everdur, and Monel metal are provided.

PETROLEUM REFINERY ENGINEER

Designer, graduate M.E. Heavy experience in design of petroleum refineries and power plants. Permanent position. Advancement possible. Major Company, New York area. Apply by letter stating age, education and business experience. Box 700 care Refiner and Natural Gasoline Manufacturer, Houston, Tex.

WANTED—for British Colony, a British Chemist, or Chemical Engineer, with experience in petroleum refining. Permanent position and prospects for right man. Apply giving details of qualifications, experience and salary required. Box 143, REFINER, Houston, Texas.

STATEMENT OF OWNERSHIP, MANAGEMENT, CIRCULATION, ETC., REQUIRED BY THE ACT OF CONGRESS OF AUGUST 24, 1912,

Of the REFINER AND NATURAL GASOLINE MANUFACTURER, published monthly at Houston, Texas, for October 1st, 1935.

State of Texas, County of Harris, ss:

Before me, a notary public in and for the State and county aforesaid, personally appeared A. L. Burns, who having been duly sworn according to law, deposes and says that he is the Business Manager of the Refiner and Natural Gasoline Manufacturer, and that the following is, to the best of his knowledge and belief, a true statement of the ownership, management (and if a daily paper, the circulation), etc., of the aforesaid publication for the date shown in the above caption, required by the Act of August 24, 1912, embodied in section 411, Postal Laws and Regulations, printed on the reverse of this form, to wit:

1. That the names and addresses of the publisher, editor, managing editor, and business managers are:

Publisher: R. L. Dudley, 3238 Huntington Drive, Houston, Texas.

Editorial Director: S. W. Robinson, 5002 Scotland, Houston, Texas.

Editor: George W. H. Reid, 1651 Danville, Houston, Texas.

Managing Editor: J. Kent Ridley, 1018 Isabella, Houston, Texas.

Business Manager: A. L. Burns, 4311 San Jacinto, Houston, Texas

2. That the owner is: (If owned by a corporation, its name and address must be stated and also immediately thereunder the names and addresses of stockholders owning or holding one per cent or more of total amount of stock. If not owned by a corporation, the names and addresses of the individual owners must be given. If owned by a firm, company, or other unincorporated concern, its name and address, as well as those of each individual member, must be given.)

The Gulf Publishing Company, Houston, Texas; James Anderson, Houston, Texas; R. L. Blaffer, Houston, Texas; Mrs. Sarah Campbell Blaffer, Houston, Texas; A. L. Burns, Houston, Texas; J. F. Carter, Jr., Tulsa, Okla.; Dr. N. L. Dudley, Goose Creek, Texas; R. L. Dudley, Houston, Texas; W. S. Farish, Houston, Texas; Wm. V. Gross, Houston, Texas; Howard R. Hughes, Houston, Texas; Chas. H. Lane, Houston, Texas; Wallace E. Pratt, Houston, Texas; J. Kent Ridley, Houston, Texas; S. W. Robinson, Houston, Texas; Mrs. Maude G. Sterling, Houston, Texas; R. P. Swinsky, New York, N. Y.; O. R. Waller, Chicago, Ill.

3. That the known bondholders, mortgagees, and other security holders owning or holding 1 per cent or more of total amount of bonds, mortgages, or other securities are: (If there are none, so state).

None.

4. That the two paragraphs next above, giving the names of the owners, stockholders, and security holders, if any, contain not only the list of stockholders and security holders as they appear upon the books of the company but also, in cases where the stockholder or security holder appears upon the books of the company as trustee or in any other fiduciary relation, the name of the person or corporation for whom such trustee is acting, is given; also that the said two paragraphs contain statements embracing affiant's full knowledge and belief as to the circumstances and conditions under which stockholders and security holders who do not appear upon the books of the company as trustees, hold stock and securities in a capacity other than that of a bona fide owner; and this affiant has no reason to believe that any other person, association, or corporation has any interest direct or indirect in the said stock, bonds, or other securities than as so stated by him.

A. L. BURNS, Business Manager.

Sworn to and subscribed before me this 27th day of September, 1935.

(My commission expires June 1, 1937.)

(Seal) J. KENT RIDLEY.